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Utilizing modern virtual reality technology in software development for city planning

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Tiivistelmä – Referat – Abstract

The use of virtual reality technology in the field of city planning has grown during the recent decades, because virtual reality provides a highly informative and immersive experience of an urban area in contrast to traditionally used 2-dimensional material, such as imagery and animations. This makes communication and decision making between the stakeholders of a city planning project much more efficient and enables participating the public to the process, which is very desirable in city planning projects.

The virtual reality technology has evolved dramatically during the past few years. Devices such as head-mounted displays, spatial controllers and CAVE installations, and developing environments, such as game engines and 3D modeling studios have become more available for consumers and developers. Therefore, the opportunities for virtual reality technology requires revisiting.
The goal of this study is to find software development opportunities for city planning projects using virtual reality technologies and realize those opportunities by implementing a model solution for use cases that show the most potential for development.

The model solution is a high-level modeling tool, which can be used for fast drafting and modeling of city-scale plans, and provides appealing visualization for presentation purposes. This allows architects to make changes to the city plan immediately as they are receiving feedback from the decision makers and other stakeholders of a city planning project. This makes the decision making much faster, as the modifications can be made during the meeting, instead of re-scheduling another meeting to see the changes to the plan. The model solution also allows viewing the plan in a highly immersive virtual reality environment, with devices such as head-mounted displays.

The development of this software is executed following well known agile methodologies used in commercial software development projects and is extended with a literature review and an analysis of the functionality of the model solution. The literature review charts the existing applications and studies of virtual reality in city planning so that opportunities for further development can be found. From these opportunities, the use cases showing the most potential are chosen and refined to a concept of an application. This concept is then refined to concrete designs and implemented in iterations, producing a final solution.

The final solution is then analyzed in a test setup, including 8 participants, who are given city planning tasks, and answers a survey afterward, affirming that the model solution is a useful tool for future city planning projects.

Avainsanat – Nyckelord – Keywords

Urban planning, city planning, virtual reality

Säilytyspaikka – Förvaringsställe – Where deposited

Muita tietoja – Övriga uppgifter – Additional information

Contents

1 Introduction

The goal of this research is to analyze what kind of software solutions are available as tools for city planning, what areas of the market of city planning tools have the most potential for development and how could virtual reality technology be utilized on those areas. Based on this analysis, a model solution for a city planning tool is designed, implemented and analyzed. Another goal of this research is to find out through an iterative design process, what features has the most value for the target group of city planning professionals, and what kind of user interface are required and desired for those features. Finally, the last goal is to evaluate the feasibility and performance of the implemented tool, in comparison to alternative tools in the market.

1.1 The nature of city planning projects

The process of city planning is a complex task. This complexity is inherent to city planning processes, and in city planning projects, the sheer scale of the subject is so large, that this alone introduces many variables. This is the reason why effective tools are critical on such projects, and on modern day's city planning projects, software tools are central on the toolkit. Problems that such tools need to address, or at least consider, are versatile.

Due to the scale of city planning projects, the amount of data is often large too, which requires performance issues to be taken into account. For instance, if the tool is a modeling tool, where a city or an urban area is modeled, the level of detail cannot be very high on the structures, when a user is examining the area as a whole.

City planning projects also involve many stakeholders with varying levels of skills in engineering, architecture, politics, communications, finances, and design, for example, all of which are skills that are required to succeed in a city planning project [Bou97, SAP08]. While tools that are used in a city planning project, does not always have to target all the stakeholders involved, the tools still often address the groups that are not targeted one way or another. An example of this is CAD software that are 3D modeling software targeted mainly for engineers and architects, but it often includes capabilities to render images and animations of the produced 3D model. These secondary outputs can be used to present the essentials of the model to stakeholders with little understanding of the CAD software.

Stakeholders also have different and often conflicting interests. Landowners may want their land's value to increase as much as possible, while architects may want to use that specific area for parks and playgrounds, which will not necessarily generate any increase in value. Take the interests of contractors, the government and the public into account, and satisfying solutions for all parties become very difficult to form, which is one of the reasons why decision making is very slow on city planning projects [Bou97, SAP08]. Some software tools address this issue by enhancing communication, making the public's desires available for the stakeholders, or calculating predictions of value changes, based on given variables. For instance, Cityfier is a software that allows users to place future components to a masterplan of an urban area and calculates value increase on a timeline on that area, based on current data and the added components [Qui18]. Such software can be used in real-time when stakeholders are negotiating about the plan for the area.

1.2 Usage of virtual reality technology in city planning

There are numerous tools to support city planning projects. An example of such tools is project management systems that help participants to keep track of progress and goals. Another type of widely used tool is data storage solutions that enable the project team to store, organize and retrieve data relative to the project. One member of the research group specifically developing city planning tools, and collaborated with this research, mentioned that by far the single most important tool to this date for him had been his email, which indicates that often city planning projects does not have a sophisticated and well established set of tools. On the other hand, there are the modeling tools that architects and engineers use to make illustrative 3D models of the city plan so that the project team can gain a better understanding of the outlook of the plan. These 3D models are also used to communicate the plan to contractors in more detail and therefore work as a medium between the non-technical decision makers and the highly pragmatic contractors.

This research, however, focuses on city planning tools, that utilizes virtual reality technologies. This exclusion limits the scope to a few main domains of use cases. Virtual reality technology-based tools in city planning can be categorized into three main categories: viewing or visualization, modeling and simulating.

Virtual reality-enhanced viewing of a city plan is, in essence, provides means for communication, which means that a 3D model, which is made by architects and engineers, can be better understood by those with less technical skills and abilities to understand the 3D models made with CAD software. Virtual reality-based visualizations can, for example, be used as a supplementary presentation to the imagery and animations that are traditionally used to present 3D models to non-technical team members.

Modeling city plans with virtual reality technology means, that virtual reality technology is somehow used in the process of creating the 3D models of a city plan. This could mean, for instance, that an architect would use virtual reality headset and spatial controllers to create a 3D model of the city plan instead of using traditional CAD software.

Simulations with virtual reality technology in city planning projects can be used to predict the outcomes of certain scenarios by simulating the scenarios forehand, which allows analysis and evaluations to be made during the planning process, and can be used to make educated decisions with given variables. Traffic, for instance, is one aspect of city planning, which is often used in simulations, to see how specific components in a city plan affect the traffic of the area.

There are also some less known use cases for virtual reality technology in city planning, which does not fall into the aforementioned categories, and these use cases will be briefly reviewed in the research. Such use cases include auditory and lighting simulations, for instance. However, this research focuses on the three main categories, and analyses which of these categories have the most potential for development. Based on these findings a model solution is designed and implemented on the category that manifests the most potential for a new tool.

1.3 Research method and structure

This research is executed combining various methods for scientific research and applying them to a software development process. This process should generate an application, which will be relevant and useful in the field of city planning.

First, to acquire sufficient knowledge and understanding of the software that has already been developed for city planning, a review and analysis of literature is executed. The review includes an overview of the history of virtual reality technology in city planning. This overview of history includes early concepts for virtual reality technology in city planning, applications that have already been developed and leaps in virtual reality technology, which has enabled new applications for city planning. The review describes an evolution of concepts and technologies, to set the stage for today's implementations and capabilities of virtual reality technology. Finally, state of the art virtual reality technology is reviewed in respect to the field of city planning, and an overview of the existing implementations is made, to gain a clear understanding of what type of solution may add value to the field of study.

The results from the literature analysis are applied to an iterative design and implementation process, which is initiated with a concepting and needfinding task, executed in collaboration with city planning experts. This process includes working closely with a group of professionals in the field of city planning and acquiring feedback about the current state of design and implementation on each iteration. The goal of such iterations is to be able to formulate as a beneficial design for the users as possible, by adjusting the initial design on each iteration according to the feedback. A temporary version of the application is implemented on each iteration resulting in the final implementation of the model solution.

The next phase of this research is an analysis of the functionality of the implemented model solution, which is done by executing tests on a group of professionals, who use the model solution to perform given tasks. Qualitative results are then formed by collecting survey data from the participants.

Finally, the execution of the overall research is discussed in retrospective. This concluding section will include a description of time and scope management in this research, a discussion about issues and benefits of the methods used and a critical examination of the topic itself, from the point of view of scientific research. Suggestions for further research and improvements to research methods are also made in this section. The overall workflow of this research is visualized in Image 1, which describes the sequence of steps performed in this research.

Image 1. Workflow of the research project

The next section is a literature review of the history of usage of virtual reality technology in the field of city planning.

2 Background and history

In order to design meaningful tools for any target audience, it is crucial to study the backgrounds of the target audience and tools that have already been developed. This chapter studies the backgrounds of the usage of virtual reality technology for the stakeholders of city planning projects.

2.1 The meaning of virtual reality

Today, the term "virtual reality" is often perceived as, or at least associated with a headset, usually combined with a head tracking system that allows the display inside the headset to mimic the experience of freely looking around in the real world by displaying parts of the virtual world in angle and position corresponding to user’s head. These headsets may be combined with a pair of spatial controllers, which can be used to interact with the virtual reality, producing an immersive experience of being in the actual virtual space. However, when research is done about virtual reality technology, some definitions are required on the matter.

The definition for virtual reality in the scope of this research is not limited to head-mounted displays or spatial controllers. As an example, in the University of Bath's Center of Advanced Studies in Architecture (CASA), the virtual reality system in place on 1997 comprised merely "a large screen display, any input device better than a keyboard and at least five to eight frames per second screen refresh rate." [Bou97] The user interface of CASA’s virtual reality application is captured in Image 2. This demonstrates that virtual reality technology is not only about devices that produce immersive experiences or intuitive spatial controllers. These are certainly used in applications of virtual reality, but they are not the essence of virtual reality itself. Virtual reality is more easily defined by its characteristics, rather than the many devices that are developed for it.

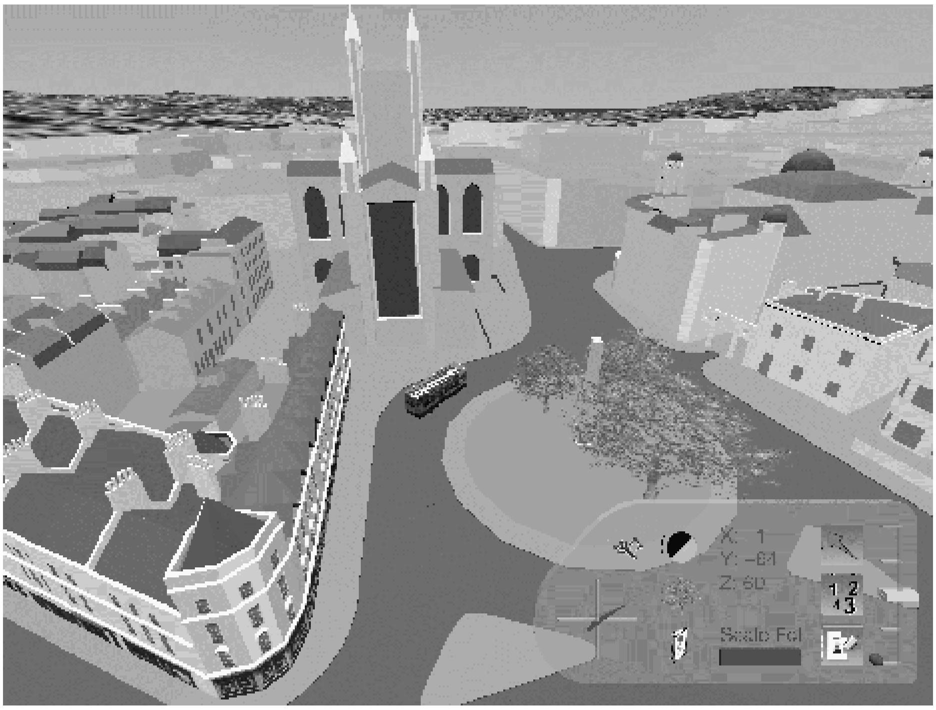

Image 2. The user interface of CASA's virtual reality application

The characteristics of virtual reality applications include such as real-time interactivity and immersion. Realistic feel is also often associated with virtual reality systems, but in the context of city planning, it is usually not an achievable goal, because of the large scale of the environments. Instead, the environments are often textured with simple colors and textures in large scale city plans, and buildings are often presented white. However, the perception of scale is crucial to be realistic in city planning projects. Therefore, this research assumes the term "virtual reality" in an inclusive sense, independent of any single display or control technologies. The characteristics of virtual reality in this research is that the technology must be interactive in real-time, but the immersion and realism of the technology are on a spectrum, and it is acceptable to have a low level of immersion and realism in a virtual reality application, depending on the use case.

2.2 *First appearances of virtual reality in city planning*

Although the term "virtual reality" has been introduced earlier in other fields of study, in computer science the study of virtual reality has been ongoing since 1965 [BBH90] and was initiated by the designing and development of a head-mounted display system by Ivan Sutherland [Sut65]. At this point, applications for virtual reality were targeted mainly for large industries, such as medical, automobile and arms industries, but in the context of city planning, it was not until the 1990's that virtual reality technology started to make its appearance. This is due to the development of computers and computational performance, which allowed virtual reality technologies to be used more widely [Bou97]. At the 1990s, universities, and enterprises began to have computers powerful enough to interact with city-scale 3D models in real-time, making the immersive usage of virtual reality technology possible. Also, the emergence of supportive virtual reality technologies, such as Virtual Reality Modelling Language (VRML), supported the efforts to implement applications to be used in city planning [Bru96].

Such efforts as UCLA's Urban Simulator in 1995 was made to utilize the virtual reality technology the modeling, displaying and evaluation of modeled urban environments of the time [LFJ95]. The Urban Simulator had some important applications, one of which was a visualization of modifications of an existing area in Los Angeles, which had previously suffered significant damage from riots and earthquakes and needed to be partially rebuilt. The Urban Simulator allowed planners and designers to evaluate modifications faster, more accurately and with a lower cost than was possible with traditional analysis. In this application, the public was also able to view and contribute to the proposed changes.

Similar efforts by the University of Bath was made targeting areas in Bath and London [Bou97]. The University of Bath started modeling the city of Bath in 1991 and parts of London in 1995 presuming that these models could then be used to help in the process of further development of the cities. These models were then used in various virtual reality tools. Such tools are presentation and evaluation tools, planning support analytical tools and real-time editing tools. The most important role of virtual reality systems, in this case, was seen as a means of communicating ideas and designs in situations where the existing real-world environment was inaccessible. In this context, the University of Bath did not see a reason to try to mimic the real world environment but merely project the relevant aspects of the real world environment to the virtual environment. This demonstrates, how virtual reality solutions do not necessarily strive for realism in all cases.

2.3 Early predictions of the development of virtual reality technology for city planning

It is interesting to reflect the current state of virtual reality technology, and its use cases to what was predicted when the earliest implementations of virtual reality systems in city planning begun to show up. This gives us an understanding of how the concepts have developed until now, and if there is a reason for some use cases to have developed more than others. This might be insightful in finding a potential tool for development as well if in some cases a tool for a predicted use case has not been implemented to this date only because the virtual reality technology has not supported the implementation of such a tool, but would be possible to be implemented with modern technology.

Many predictions are associated with communication between stakeholders in the project, which is predicted to improve in the future [Bou97, LFJ95, HG07]. Some predictions speculate that in the future there may be meetings arranged, where experts around the world would participate in a virtual reality base meeting [Bou97]. While there have been some efforts to this direction, a legitimate argument could be made that such a tool would not be specific to city planning applications, or even virtual reality applications. After all, tools virtual meetings have existed for a long time, and screen sharing and other such features have been implemented, so it is a valid assumption that such tools for virtual reality systems would not be specific to city planning. It may be that development predictions to this direction are due to the high interest in the development of the internet in the 1990s.

Some predictions in the 1990s believe that the virtual reality-based city planning tools would have well established best practices and standards for virtual reality model creations [Bou01]. The conventions of 2D based workflows are predicted to be translated and extended in virtual reality based workflow, and guidelines for creating 3D models for virtual reality are predicted to be made. While some efforts have been made in this branch and it would undoubtedly be an important subject of study, the prediction has not yet fully realised. Reasons for this is hard to assume, but it may have to do with how fast the technology has changed, how diverse the supporting devices and software are and also how little the virtual reality tools are still used in today’s in city planning.

Predictions of the 1990s accurately assumed that the immersion of virtual reality implementations is going to improve significantly. The performance of early day's implementations was not very good, and it was argued that at that time interactivity was an issue and that the systems were not immersive and were often disorienting [Bou97]. As the virtual reality technology has developed dramatically in the past few years, these are not major issues anymore.

In addition to the visualization solutions developed in the 1990s, some discussions predicted that fully editable virtual reality tools would be available in the future. There have been some studies and products that support modifying the models in a virtual reality environment, but this has not yet been a very successful branch of development [LFJ95]. There were not many virtual reality city planning simulations in the early 1990s. Some papers discuss the virtual reality simulations, but they often mean the mere immersive experience of a user being in the virtual environment, as is in the case in UCLA's Urban Simulator. In the late 1990s, the city scale simulations combined with virtual reality technology begun to have some interest and was seen to have tremendous opportunities as technology evolves. However, not much research on this field was made at that time.

2.4 *Significant implementations and studies of virtual reality-based city planning tools*

Solutions for virtual reality tools for city planning have evolved since the early implementations in the 1990s. To be able to understand the current trends, it is important to reflect on the course of development through in the past. Here are some highlights of applications for virtual reality technology in the context of city planning from the past three decades.

The earlier mentioned Urban Simulator, by UCLA's Department of Architecture, developed in 1995 [LFJ95], is one of the first produced city planning tools that utilize virtual reality technologies. This ambitious project integrated two-dimensional GIS data with CAD models to create high quality photo-realistic virtual reality experiences. The system utilized aerial photographs and street-level videos to apply textures to the landscape and the 3D models. These virtual environments could then be used for walk-through or interactive fly demonstrations of neighborhoods. The intention was to be able to engage the public in the decision-making process, provide means to communicate with the communities living in the subject areas. The Urban Simulator allowed the planners to remove buildings in the modeled areas, modify roads and add parks and greeneries to the areas, experiment with alternative designs. The GIS integration also allowed information to be drawn from specific buildings in the virtual reality. Such data may contain information about the building's ownership, type, the owner's willingness to work with the community for further development and even information about government grants for further development in specific areas. Having all this information immediately available, made planning and decision much faster. Urban Simulator was also used to simulate the effects of a law change, which would require property owners to plant trees in front of their properties. The effects were modeled to the virtual reality model and predicted property value changes were added for each property, so now the users were able to experience what the neighborhood would look like after the law change, and how the property values would change over time. The integration of GIS and CAD data is displayed on Image 3, where the colored areas visualizes the result of a user-executed query on the model.

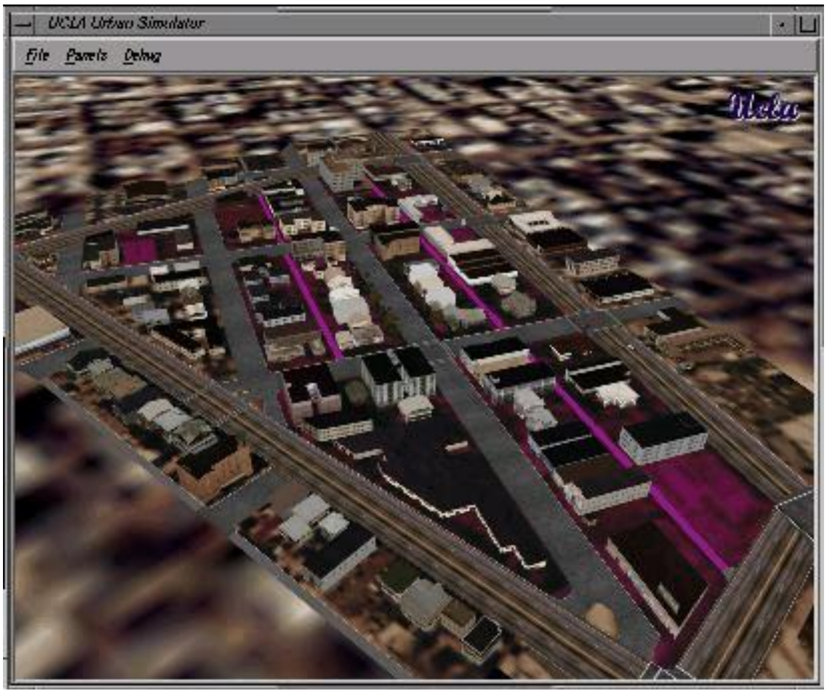

Image 3. UCLA's Urban Simulator

Another impressive effort towards using virtual reality technology in city planning was a commercial application targeted for industrial use by by Matsushita Electric Works, Ltd. in 1999 [NS99]. While Matsushita Electric Works have made multiple applications using head-mounted displays for other industries, such as relaxation system for healthcare, horseback riding simulator for therapeutic use, and kitchen design system for kitchen markets, the application made for city planning did not actually utilize head-mounted displays. Instead, the city model was reflected on a large dome-shaped screen, displayed on Image 4, by six stereoscopic projectors. This enabled a stereoscopic picture with resolution as high as 3086 x 1536 pixels, which was not possible with head-mounted displays of the time. Plans were also made to implement a stereoscopic sound and voice input system, but whether this work was finished, is not clear. The dome system is a practical way of viewing the virtual environment in collaboration since the isolating effect of head-mounted displays is not present. This installation resembles modern day's Cave Automatic Virtual Environment (CAVE) installations a lot, and arguably this could be called a CAVE installation as well. In addition to the dome-based viewing installation, Matsushita Electric Works developed a distributed presentation system, which allowed specialists and citizens to participate regardless of their physical location, given that they are interconnected with a high-speed internet connection.

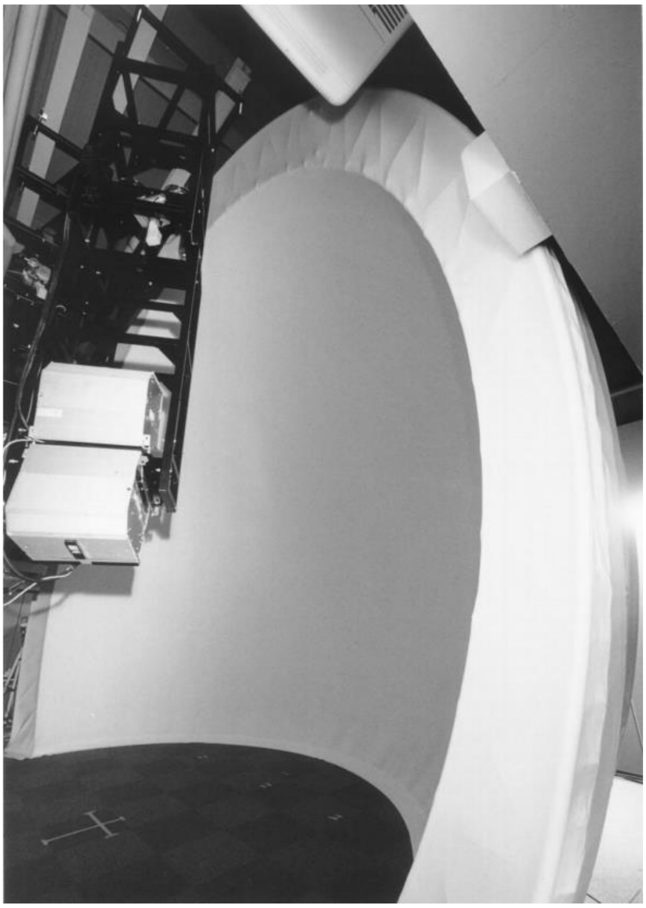

Image 4. Matshushita Electric Works' CAVE installation

An extensive study about GIS and virtual reality integration was done by Huang et al. in the Chinese University of Hong Kong in 2000 [HJL01]. In contrast to the research made by Matsushita Electric Works, this was a more theoretical and technical study, that explored the possibilities with integrating GIS systems and virtual reality technology with VRML. The study has gained fair amount of attention, and it lays out a fair amount of definitions, such as VRGIS and Networked VR, for new concepts that were not yet well established. The study also considers many modern technologies of that time, which makes this study stand as great reference for later studies. This study produced a toolkit, called GeoV&A. GeoV&A enables the user to use 2D GIS data as input, and automatically extrude elements on the GIS data to a 3D representation. The user is also able to set heights and attributes to the GIS elements manually, changing the 3D representation as well. This 3D representation is then translated to VRML, which is consumed in a WorldView plug-in to enable the user to navigate and view the model in virtual reality. This solution is therefore much more advanced integration of GIS data and virtual reality technology, than the previously mentioned Urban Simulator. GeoV&A also implements a number of geographical analysis functions based on terrain surfaces, an example of which is a profile graph creation tool, displayed in Image 5, which allows the user to draw a line, and a height function of that line is translated to a graph. Another example of an implemented analysis function is a viewshed analysis, which identifies whether some specified observation points are visible from each cell on the surface and vice versa. Such an analysis function has many use cases, such as the design of a cellular network or placement of military troops. This is one of the earliest studies, which integrates extensive analysis capabilities with virtual reality technology in the context of city planning, and is, therefore, a significant landmark in the development of city planning virtual reality technology.

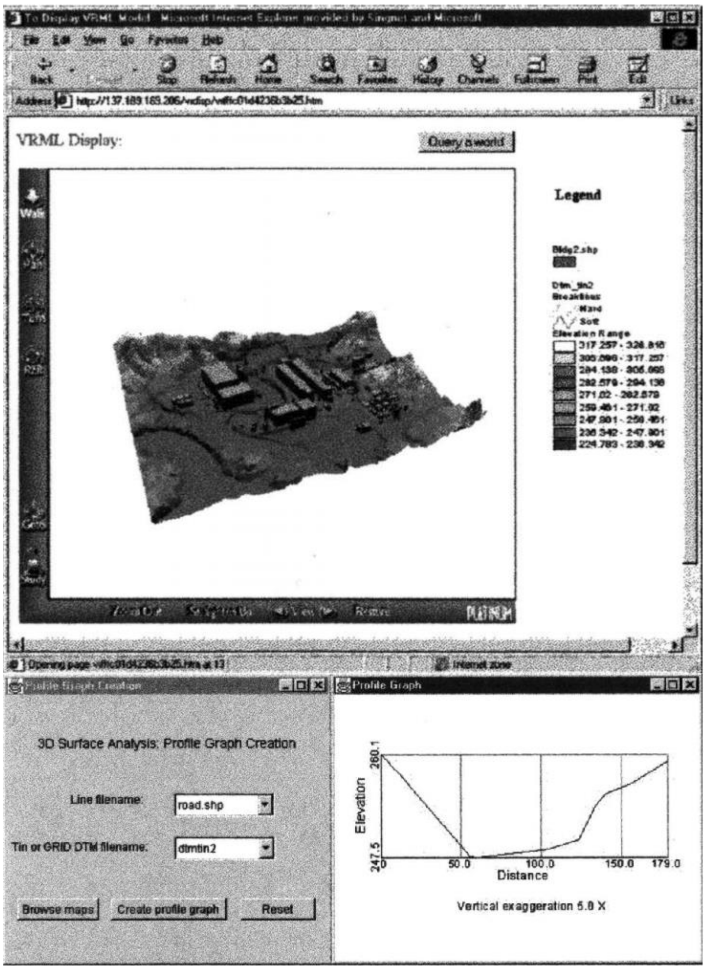

Image 5. Profile graph creation tool with GIS and VRML integration

The evolution of implementations of virtual reality technology in city planning continues, and by the late 2000s, some use cases for virtual reality technology are becoming more established. Participating the public is one of these use cases, and in this field, a study with experiments with 25 participants was executed by Howard et al. in 2007 [HG07]. The study pointed out a few issues with more traditional ways to engage the public: lack of interactivity, in terms of the user not being able to navigate and browse the plans freely. The second issue is the lack of immersion. In small-scale physical models, the scale may be hard to perceive. On the other hand, with 2D based material, such as imagery and animations, it is hard to feel immersed inside the environment, since the medium lacks the freedom of viewing the model on the user's terms, as with the issue of lack of interactivity. The third issue is the limited commentary from the public, and those comments that are received lack precision since they usually are written on a notebook in an informal manner. The study aimed to address these issues and proposes that virtual environments and virtual reality technology may offer a solution. In the model solution of the study, the virtual environments contained both 3D models of the plan as well as textual information, which may have a spatial location in the environment, demonstrated in Image 6, which is a screen capture of the user interface of the model solution. Users were also able to interact with the plan, by altering the model or altering the text data related to the model. This allowed the participants from the public to make some modifications to the model, and write their feedback on notes within the model, and in that way present their own model solutions for the subject city plan, instead of merely giving textual suggestions and feedback. Three aspects were emphasized in the evaluation. First is performance, and since the solution should be available for the public, the experiments were run on standard home computers to examine the performance. The second issue in the evaluation was usability because the system needs to be usable for the public, so no particular skillset or previous experience should be required. The third point of interest in the evaluation was the overall interest in the approach the model solution was suggesting, which is an important point to evaluate. Without evaluating the interest for such a system, scientists may develop great solutions that perform very well on laboratory tests, but will never be used because of the lack of appeal to the target audience. In addition to the laboratory tests of 25 people, a general public survey was executed, to validate the key points of evaluation. The result was that indeed with the proposed solution the test subjects were able to participate in the city planning process and give consultancy to the planning team with ease. The general public survey validated that there is an interest in participating in city planning projects with an application described in the study. This, and many other similar studies demonstrates that communication between the stakeholders in a planning process, especially with the public, is a use case of high interest with virtual reality technology in city planning, and much effort has been put to enhance the engagement of the public, and communication among the stakeholders.

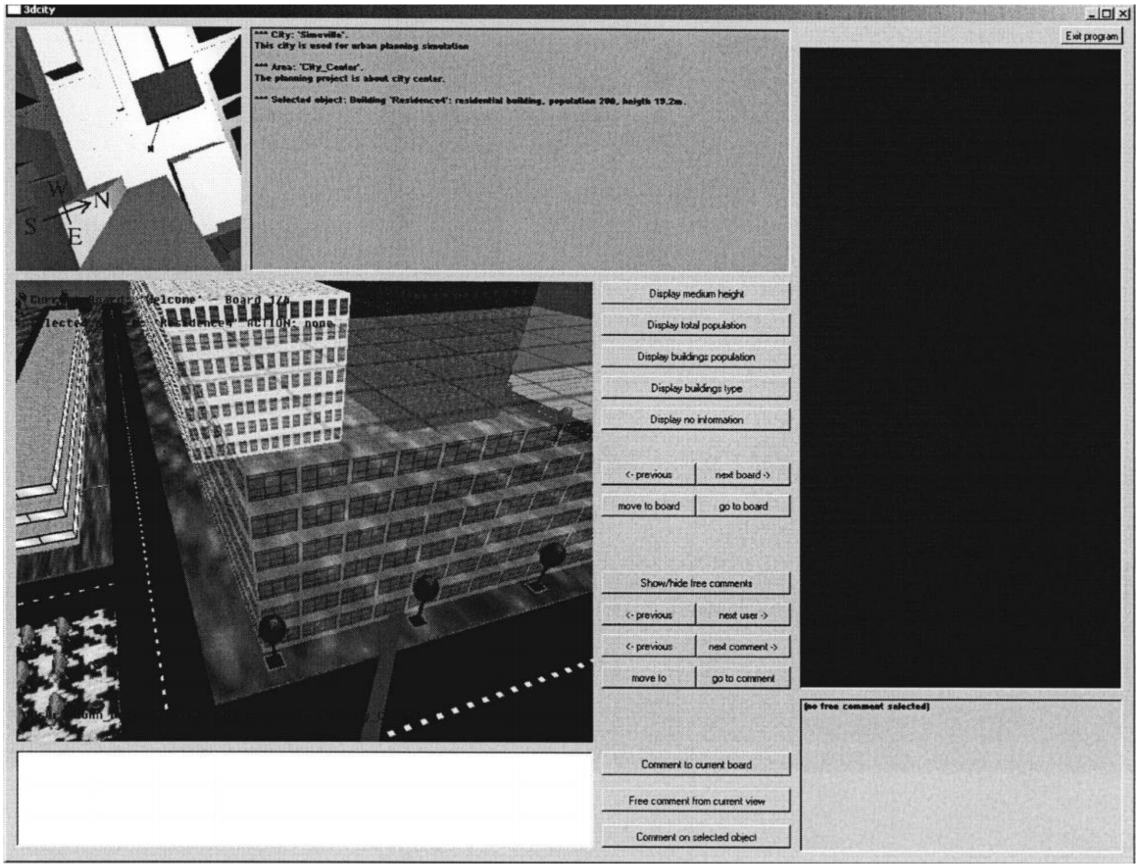

Image 6. User interface of virtual reality-based public participation tool

All the aforementioned studies have presented implementations of virtual reality tools for city planning, which focuses mainly on visualizing the city plan. Some studies have also implemented features for minor modifications in the virtual environment and various solutions for engaging the public to the decision making process. However, in 2008, a study made by Chun et al. of the Ocean University of China researched a different type of use for virtual reality technology. The study focused on traffic, which is an important part of city planning. In this study, virtual reality technology was implemented in a traffic simulation application, displayed in Image 7, to communicate alternative designs to decision-makers and the public [CYH08]. The simulation parameters included roadway networks, traffic control systems, and driver-vehicle units, controlled by various behavioral models. VISSIM was used to orchestrate the simulation, and VR4MAX to create the virtual environment from 3D models. The simulation was validated by giving input parameters of the current traffic situation and compare the outputs to field data of the actual traffic situation. After validating the functionality of the simulation, three different future scenarios were evaluated, where various changes to the city's infrastructure were made. The study was found to be successful, and it demonstrated that city scale simulations with virtual reality technology are presentable and usable to the public, unlike in earlier non-immersive simulations, which were targeted to professionals, rather than the public. This is one of the earliest studies in city scale simulations with virtual reality technology, and is a good example of the capabilities of virtual reality technology in simulation usage. Even though some simulations in virtual reality had been implemented much earlier than this, they were targeted in different fields of profession, and it was not until the late 2000s when the computational performance started to be sufficient enough to perform with city-scale simulations.

Image 7. Virtual reality-based traffic simulation tool

The studies and implementations described previously presented some of the highlights of the development of virtual reality tools for city planning. There are also many interesting implementations and studies in the mid- and late 2010's, and they will be discussed later in this study. It is worth noting that many of the use cases that are still studied today were actually designed as concepts in the earliest days of city planning virtual reality tools. As the performance of available technology improves over time, new iterations to these concepts have been made, and on each iteration, some goals have been achieved, which were not possible to achieve earlier. However, it seems that features of virtual reality, that has demand in city planning projects, have not changed drastically in the past few decades.

2.5 Leaps in virtual reality technology during the development of virtual reality tools for city planning

Over the last few years, virtual reality technology has developed dramatically. There are large companies making this technology for consumer usage, and this enables more resources to research in this field and raises the interest of the public on the topic. Technology for virtual reality applications has, however, been around for some time already. By understanding what kind of technology we have had in the past, and which of those technologies have survived the evolution of the field, we can better understand what type of technologies have demand in the markets. This allows cutting the branches of design in our own applications, that have already been experimented with poor results. Here are a few examples of the leaps in technology of virtual reality.

One of the earliest landmarks of virtual reality in computer science was the invention of the head-mounted display, "The Ultimate Display" by Ivan Sutherland in 1965 [Sut65], and it was implementation a few years later in 1968. Sutherland describes the task of a display to be "a looking-glass into the mathematical wonderland" of the computer, and he points out that the movement of a joystick, which was previously used to interact with the computer, could be computer controlled by tracking muscle movements of hands and arms. Similarly, he suggests that eye movements could be tracked, and the display could be adjusted accordingly. This is one of the most famous works that has been made in the field of virtual reality, and some claim that this is the start of the development of virtual reality technology [BBH90].

Other significant leaps in virtual reality technology were made by VPL Research Inc. in the late 1980s [LBC88]. VPL Research created DataGlove in 1987, which was an input device for computers, that sensed finger and joint movement, and was later used for virtual reality applications. In 1988, VPL Research created DataSuit, which was a tracking system for the movement of the whole body and could similarly be used in virtual environments. The company also created a head-mounted display, called the EyePhone, which is displayed on Image 8, where a mannequin is wearing the DataGloves and the DataSuit with the EyePhone. VPL Research claimed that these devices could be used in virtual reality environments for training simulations, education, virtual teleconferencing, and entertainment. VPL Research even created a platform for developing virtual reality applications, called Reality Built for Two (RB2) [BBH90]. This platform consisted of a number of modules and devices, including the EyePhone and DataGloves as well as thirdparty components and devices. VPL Research's goal was to provide virtual reality experiences to large audiences; however, the company went bankrupt in 1990, even though it was a significant developer of the virtual reality technology at that time. This may indicate, that devices such as haptic suits are not consumer friendly products, which would be used in everyday life.

Image 8. VPL Research's DataGloves, DataSuit and EyePhone

With the VPL Research's efforts, development for general use platforms and standards for virtual reality technology had begun. In 1994, Virtual Reality Modelling Language, or VRML, was developed and standardized [Bru96]. VRML is a 3-dimensional representation of interactive vector graphics, specifically designed for internet use. This was a significant step towards well established and standardized practices of virtual reality technology and is used in many implementations, as mentioned earlier. The interest in standardization can also be seen in many other studies. An example of this is a study by Bourdakis in 2001 [Bou01], where he establishes a proposal for a number of standards specifically for virtual reality models in the context of city planning.

This was a brief review of the evolution of virtual reality technology. After these innovations and installations, there have been many studies in the same directions, researching haptic input devices, CAVE installations and head-mounted displays. The most recent technology developed will be discussed later in this research. However, even this short review of the past implementations reveals, that, just like the concept of virtual reality in city planning, virtual reality technology has been around for quite a while, and that from the user's perspective there hasn't been a lot of new innovations, when comparing the modern day's devices to the earlier virtual reality products. Head-mounted displays and spatial controllers are as relevant today, as they were in the 1960s.

This chapter included a review of the backgrounds and history of virtual reality technology, and it is used in city planning. The next section is a review of the virtual reality technology available today, and modern implementations for city planning tools utilizing that technology.

3 Current implementations and technologies of virtual reality in city planning

Virtual reality technology has developed greatly during the past few years. As the prices and sizes of electric components have gone smaller, manufacturers have been able to produce virtual reality devices that are consumer friendly, in terms of both price and usability. The technology has also evolved in the development platform markets, which supports the development of new city planning virtual reality applications considerably. This shift in technology allows new types of applications to be implemented using the modern technology, and this chapter discusses both, the capabilities of modern technologies and city planning applications implemented with that technology.

3.1 Modern virtual reality tools for city planning

This section reviews some studies and tools targeted for city planning, using modern virtual reality technology. The intent is to gain an understanding of what can be achieved with today's virtual reality technology, and what kind of problems are addressed today in the context of city planning.

One topic in virtual reality applications for city planning is the use of multisensory output devices. This idea was already introduced by Sutherland in his paper ”Ultimate Display” [Sut65], but with the popularity of virtual reality applications growing, this domain attracts more research efforts. In addition to visual output, auditory output has gained an important role in virtual reality applications for city planning. An example of such application was implemented by Maffei et al. of Seconda Universita degli Studi di Napoli in a study of virtual reality as a tool for multisensory evaluation of urban spaces [MMP15]. The study was able to validate that with both, visual and auditory outputs, the experience was immersive enough that the perception did not differ significantly from a real-world scenario. The study especially pointed out that the quality of the auditory experience was very similar to the real world experience, in terms of qualities such as pleasantness, chaotic, calm, boring and vivacious. Some studies also investigate other multi-sensory output devices, such as tactile output and olfactory output [ZEO99, Gut10].

One common issue that city planning projects face is the long cycle of making architectural changes to the plan. A current version of a plan may be discussed and evaluated in a meeting or collaborative workshop between the stakeholders, and modification suggestions are often made about the architectural design of the plan. These modifications may be a small task for the architect to make; nevertheless, a new meeting has to be decided where the modifications are evaluated, hence the cycle of making even small modifications may be very long. A study by Nguyen et al. of the Ho Chi Minh City's University of Science addresses this issue in an innovative manner [NNV]. The study produced an application that could be used to design and visualize city plans fully in virtual reality. The application allowed multiple users to view the same city plan via the internet. The users could design the city plan from scratch by first designing a road network of a city, after which they could automatically generate city areas that consist of buildings emulating city blocks, as displayed in Image 9. This allows the users to create city scale plans extremely fast, without having to model each building in the city separately. After autogenerating the city areas, the user could then modify the areas according to the decision makers' wishes. The application also implemented interactions with Leap Motion, which allows gesture-based interactions in the virtual environment, making the interactions intuitive and usable not only for architectures but other stakeholders of the project as well. The most impressive aspect of this application is that the designing and visualization can be done immediately in the same space and time with all stakeholders present in the virtual environment, connected via Internet. With such an application, the long design loop of weeks or months does not exist, and the changes can be made instantly, making decision making much faster in city planning projects.

Although this application has many shortcomings in its capabilities to design roads and autogenerating specific kinds of city areas, the concept is very impressive, and with further development, this could indeed transform the city planning process to be much more efficient.

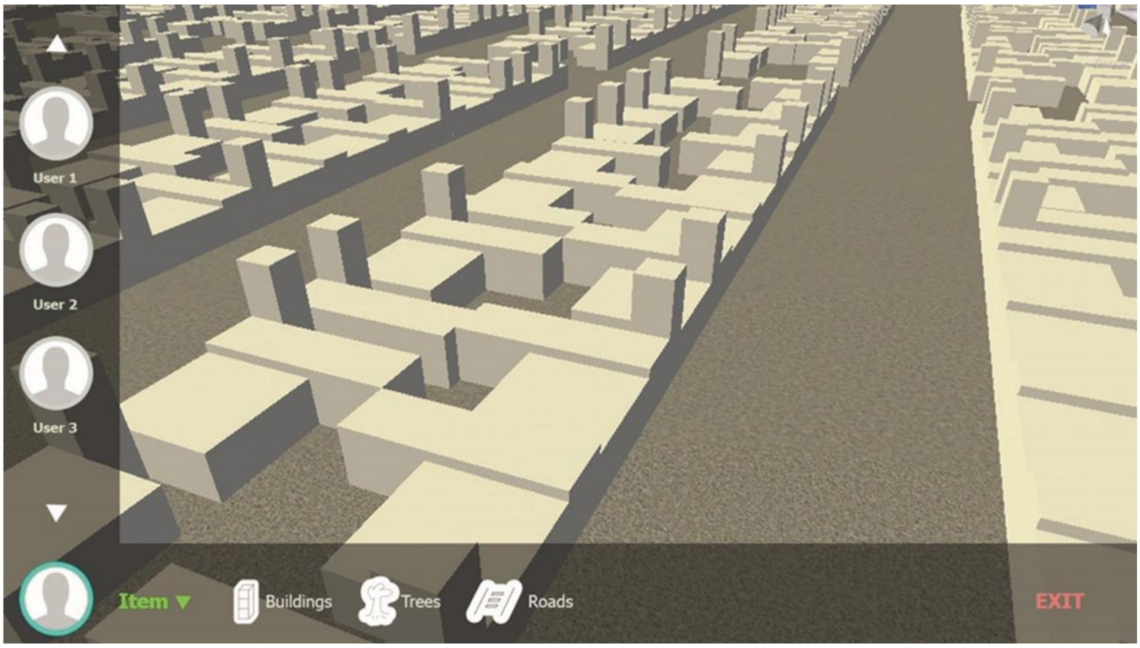

Image 9. Automatically generated city layout

The use of virtual reality technology in architectural city design and modeling, is a category of virtual reality use cases that have not been studied as much as visualizations or simulations. This may be because architects are professionals with highly developed workflows, and are comfortable with their current way of working [SAP08]. Therefore there may not be a reasonable justification for a completely different workflow for architectural design. However, Ruben Hanssen studied the possibilities of virtual reality-based urban design tools in his thesis "VRbanism: assessing Virtual Reality as an urban design tool." [Han17] While Hanssen successfully implemented virtual reality-based tools for creating and modifying city models, he found that the design process was very demanding. The virtual reality-based workflow lacked the precision of traditional modeling tools, and the users would often interact with wrong elements, and overall, the interactions required great effort in comparison to traditional modeling software. Sample city design modeled with this tool is displayed in Image 10, which demonstrates that coarse models can indeed be modeled with this tool for high level urban planning purposes. Another issue with designing in virtual reality with a head-mounted display and spatial controllers was that it was physically a very demanding task. Because of many large arm movements required, modeling was so intensive that two hours of modeling seemed to be a natural limit for a person to be able to design and model urban areas with this application. Hanssen concluded that virtual reality in city planning is great for improved spatial overview and perception of scale, and can be useful to get direct feedback on morphological and appearance-based design choices, but he found that virtual reality technology does not necessarily support creating city models very well. However, this may be due to implementation decisions Hanssen made in his application of virtual reality city planning tool, and with a different approach to the application's interactions, a more usable implementation may be achievable for city modeling in virtual reality.

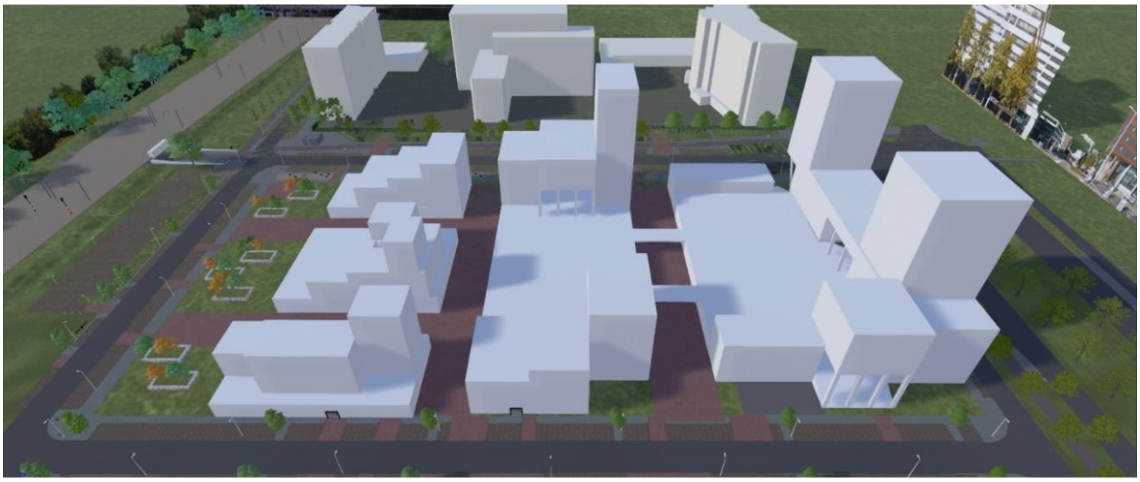

Image 10. Custom city design made in virtual reality using spatial controllers

Other applications of modern virtual reality technology in city planning are simulations and analysis tools. Virtual reality technology has been used for simulations from the earliest days of virtual reality, for example in flight simulations. In the context of city planning, virtual reality has been used in numerous simulation and analysis scenarios, such as traffic simulations mentioned previously [CYH08]. Other examples of simulation and analysis use cases for virtual reality in city planning are a satellite performance simulation in cities [WGZ12], an auditory simulation based noise analysis for designing public space [SRS17], flooding and thermal stress evaluation [BVC17], visibility analysis, emergency response and hazards planning [BSL15, Sim01] and IoT and big data analysis using virtual environments [LYZ16]. These types of implementations of virtual reality requires not only deep knowledge of the field of city planning but also the specialization to the subject that is being simulated or analyzed, and for this reason these types of implementations are out of the scope of this research, and won't be considered in the needfinding process for a virtual reality city planning tool.

Virtual reality has also used in educational purposes in city planning, as UCLA's Urban Simulation team demonstrates in their educational and historical reconstruction projects, such as the Trajan's Forum, the Jerusalem's Temple Mount and the Columbian Exposition of 1893.

3.2 Modern virtual reality technology relevant to city planning

As mentioned before, there has been impressive developments in virtual reality technology in the past few years. Large enterprises, such as HTC, Oculus, Facebook, Sony, Unity and Epic Games have been able to improve their technology to the point that it is now available for consumers and developers in terms of price and usability. Not all virtual reality technology is suitable for the use of city planning though, such as virtual reality weapons, used in gaming, but here is an overview of the technology that may be suitable for some use cases in city planning.

3.2.1 Head mounted displays

Head-mounted displays cannot be avoided in discussions of modern virtual reality. In the past, virtual reality could be conceived as a computer-generated, virtual environment, viewed through a traditional monitor. However, today the virtual reality is often understood as an environment viewed through head-mounted displays, and for a good reason. The technology of head-mounted displays has developed to the point, that the viewing experience can be truly immersive.

At this moment, Oculus Rift and HTC Vive, displayed on Image 11, are dominating the market of head-mounted displays. They both offer an impressive resolution of 2160 x 1200 pixels with a refresh rate of 90 Hz. This enables applications to be relatively sharp, and the high refresh rate enhances the immersion so that the camera viewpoint responds to head movement very quickly and looking around the virtual environment feels natural. Both devices also have a 110-degree field of view, which is well enough to produce an immersive effect. To further enhance the immersion, these head-mounted displays even tracks the relative position of the user's head, so that user's movements in the physical world are translated to movements in the virtual environment. The cost of these devices varies around 400 - 800 USD, though a computer with sufficient performance is required to run virtual reality applications with these devices, which might cost well over 1000 USD. Nevertheless, the price range is still consumer friendly.

Image 11. HTC Vive and Oculus Rift headsets and spatial controllers

There is another category of head-mounted displays utilizing modern smartphones. There have been several products that allow the user to attach their smartphones into a headset, and use the display of the smartphone as the display for virtual reality, and sensor in the phone to track head movement. Such products include Samsung Gear VR, Google Cardboard, Google Daydream View and Merge VR Goggles, to name a few. The price for these headsets varies from 5 USD with Google Cardboard to 130 USD with Gear VR. While head-mounted displays utilizing smartphones are limited by the smartphone's performance and screen quality, they still make a good alternative for virtual reality experiences in city planning, especially for mere visualization purposes, if a lot of navigation and interactions are not required.

3.2.2 CAVE installations

CAVE installations are a popular way of viewing virtual environments in city planning projects. CAVE installations usually consists of multiple projectors, which projects the image on a curved or multi-sided silver screen, displayed on Image 12, resulting in wider field of view and enhanced immersion, compared to single projector setups. There are many companies offering installation services for CAVEs, like Visbox and Virtual Domes, for instance, which both have their own approach to CAVE installations. The reason why

CAVE installations are popular specifically in city planning projects is that they allow a group of people to stay in the same space, see and talk to each other, without the isolating effect of head-mounted displays. The drawback of CAVEs is that they can be quite expensive, and requires a lot of space. While the immersion with CAVE installations can be fairly good, especially if used with stereoscopic displays, they do not compare to head-mounted displays in terms of immersion, because the display composition is often not perfectly seamless, and the user may see elements of the real world while looking at the virtual environment, breaking the immersion. However, with today's high-resolution stereoscopic projectors with high refresh rate, a fairly immersive experience can be produced, and CAVEs can be very useful for keeping meetings about the city model with a small group of people.

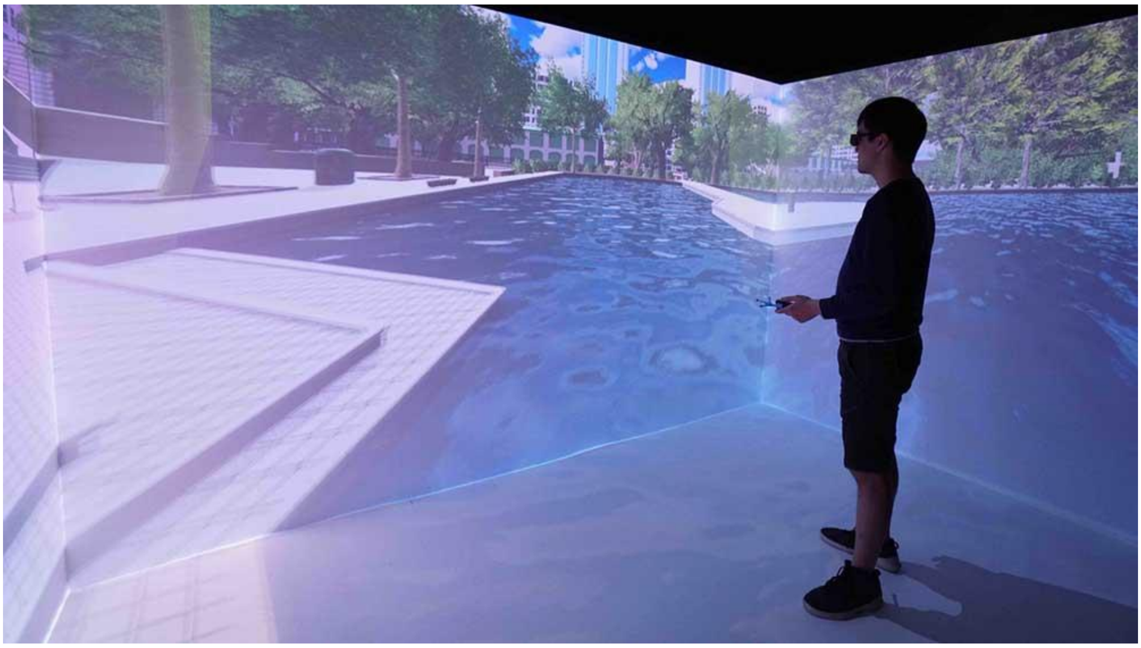

Image 12. Example of a CAVE installation

3.2.3 Virtual reality controllers

While many virtual reality applications may be used with traditional input devices, like mouse and keyboard, in many cases they are not ideal. Especially with head-mounted displays, keyboard and mouse can be very clumsy to use. Various types of spatial controllers have been developed for this purpose. Oculus Rift and HTC Vive both include a pair of spatial controllers, displayed in Image 11, that tracks the location and angle of the controller with up to 1 kHz refresh rate, making them easy to be used and even rendered in the virtual environment in real-time. The controllers include several buttons and controls for different types of interaction. This type of controllers are the most popular controllers to be used with head-mounted displays.

Another type of controller specifically targeted for virtual reality applications is motion-sensing controllers. Leap Motion is an example of such a controller, which tracks the movement of hands with infrared technology so that the controller detects the movements without the user having to touch the controller. Image 13 demonstrates how Leap Motion tracks hand movements and translates them to 3-dimensional space. The interactions with such a controller are based on hand gestures, where the user can, for example, interact with an object by pinching it in the virtual environment. This type of controllers have not been as popular as other spatial controllers, but some applications have been implemented for city planning using these controllers, as was demonstrated in the previously mentioned study by Nguyen et al. [NNV16]

Image 13. Leap Motion tracks hand motion with infrared technology

Other types of controllers are also developed for virtual reality, an example of which is haptic gloves, provided by HaptX, Plexus Immersive, and VRGluv, for instance, but these controllers do not seem to have much demand in the field of city planning. In the author's opinion, these could have potential in city modeling applications in virtual reality, since they could have much more precision in the interactions than the common spatial controllers, and since the lack of precision is exactly one of the main issues with city modeling in virtual reality, as Hanssen pointed out [Han17], haptic gloves could solve those issues.

3.2.4 Development platforms and libraries for virtual reality applications

From the point of view of software engineering, probably the most interesting developments have happened in the software development environment technologies. Improvement in the development environments greatly reduces the efforts needed to create virtual reality applications, and even allows people who are not experts in programming to build virtual reality applications to some extent.

Game engines of today are supporting the development of virtual reality applications with ease. There are plugins available for game engines that allow programmers to implement virtual reality-specific interactions to their software. To build virtual reality applications with Unity or Unreal Engine, for instance, the developer merely has to set the target platform to be some virtual reality device, such as Oculus Rift or HTC Vive. Obviously, the application has to be designed accordingly, to provide an acceptable user experience.

In addition to game engines, most 3D modeling software also supports the creation of virtual reality applications. Modeling software, such as 3DS Max, Maya, Blender, and SketchUp are already used to create the 3D models for the virtual environment, so for the architects it may be natural to use these tools to build their virtual reality applications. Though, as the 3D modeling software are not designed for creation of real-time interactive systems, they may lack some capabilities of the aforementioned game engines in terms of UI and interaction design for the virtual reality application.

There are also many libraries that help developers create virtual reality applications in scripting languages. Examples of such libraries are Three.js, React VR and A-Frame, which are JavaScript libraries and can be used to create virtual reality applications for the web, although other target platforms are possible as well with JavaScript. While these kinds of libraries may not be as complete and sophisticated as development environments like game engines, these kinds of libraries make it possible for developers to make, with little effort, small virtual reality applications that can be easily distributed and used in the web.

As the interest for virtual reality technology has increased drastically after the upcoming of modern head-mounted displays, some secondary platforms for making virtual reality applications have also started to show up. InstaVR is an example of such a platform. It allows a user with no technical skills to create virtual reality applications using a web-based platform. However, the applications are only limited to viewing applications of 360 videos, but this demonstrates the public's interest in making their own implementations of virtual reality. Arguably InstaVR could also be used in the city planning process, as non-technical participants of the project could make 360 videos of existing urban areas, and make them available through an application created with InstaVR. Another example of a virtual reality platform targeted for people with less technical skills is Appy Pie's AR/VR App Builder, which works in a similar way as some content management systems, like WordPress. The usefulness of this kind of platform, especially in the context of city planning, is questionable though.

This chapter was an overview of modern virtual reality technology, and how it has been used in some implementations of city planning tools. The next chapter describes the design and implementation process executed in this research, the final design, and some implementation details of the system.

4 Development of a model solution for a city planning virtual reality tool

This research includes designing and implementation of a model solution of a city planning virtual reality tool. The previous literature review is used as a starting point for the design of the tool and is analyzed to find out what kind of application would add value to the city planning process, in respect to existing virtual reality tools for city planning. When a viable idea for an application is found, this idea is then validated and refined with experienced stakeholders of city planning projects. After this, an application is designed, based on the refined idea, and finally, the design is implemented in an initial version of the tool. This whole process is performed in an agile manner, and after the initial implementation is ready, it is then presented to the same group of stakeholders that participated in refining the initial idea. Feedback, regarding the initial implementation, is gathered from the stakeholders and used to refine the design of the application. Such iterations are made until the implementation is at a satisfactory level. This workflow follows the iterative planning process method [Num07]. The overall development workflow is demonstrated in Image 14.

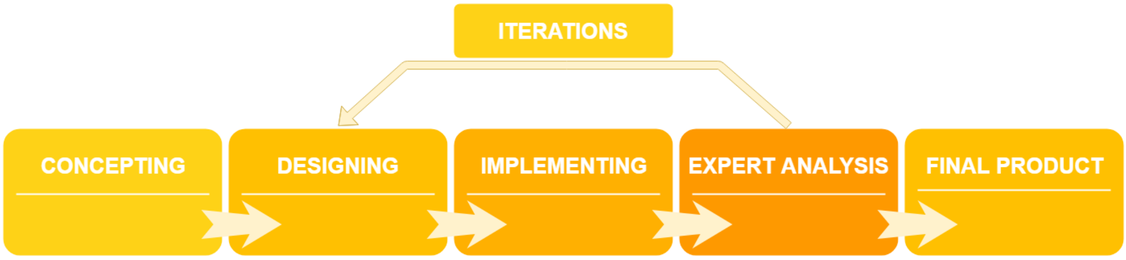

Image 14. Development workflow

4.1 The initial concept for a virtual reality city planning tool

After an extensive literature review of the usage of virtual reality technology in city planning is performed, a concept for an application with market value can be made. Such application should be one, that has not been already made and one that will solve some issue in the current city planning processes.

Since a lot of research and effort have already been put to pure visualization solutions for city planning, this did not seem to be the most useful category of virtual reality applications to be explored in the context of this research. However, there are some aspects of visualization, that has been recently made available by modern development environments. An example of such aspects is the path and hue of the sun at different times of year in different locations in the Earth [BSL15]. Such visualizations have gained interest by decision makers in city planning projects, because it may have an impact on design decisions, especially when designing park and greenery areas. Another example of aspects of visualization available with today's technology is shadow analysis [BSL15], which allows the users to see how shadows will cast during the day and year in the subject area. This is an important aspect to take into account in city planning, so that, for instance, the effect of building a very high tower in the area can be analyzed, and if the building would cast a shadow on a park area for most of the year, then it's placement could be adjusted accordingly. Depending on the government, even regulations may exist for taking the shadows into account in the city design.

In contrast to visualization tools, virtual reality modeling tools for city planning do not have many applications. Although there have been some studies in this field, there are no commercial products in the market that would enable users to perform city scale modeling in virtual reality. There may be good reasons for that, one of which is that the architects designing the cities have well-established workflows, and are able to perform very well with the traditional tools [SAP08]. However, the literature review proves that designing and modeling city plans in virtual reality can have some benefits over traditional tools. Virtual reality-based designing tools are easier to use and are suitable for people with a low level of technical skills. These applications also have inherent capabilities to present the city models in an immersive manner, improving the perception of the plan. Therefore, a well-designed combination of modeling and visualization tools with virtual reality technology would be a powerful tool for city planning.

The third branch of virtual reality tools for city planning is simulation tools. While these kinds of tools are very valuable to support decision making in city planning, they require a high level of knowledge of the subject of simulation, as mentioned earlier. For this reason, such applications were not considered, when designing the concept for a virtual reality city planning tool in this study.

The initial design of the tool was now decided to be a tool that combines visualization and modeling capabilities. In addition to simple navigation capabilities, the visualization features would include basic functions to analyze the shadows cast by the sun in the city model. The modeling in virtual reality should be very simple since the precision of interactions is an issue in virtual reality. Moreover, as Hanssen pointed out, spatial controllers make the designing process physically very demanding [Han17], so the mouse and keyboard were decided to be the main input devices for the modeling in this application. After all, the concept of virtual reality is not limited to head-mounted displays and spatial controllers in the context of this research. The initial concept also included a catalog of buildings in the UI, which could be used to easily drag and drop buildings and city blocks to the terrain, making the modeling process fast-paced. The idea was to enable users to present and examine the city plan while it would be simultaneously modeled by other users. The setup could be constructed, so that an architect would have a separate monitor and keyboard and mouse, which he/she could use to make modifications to the model while getting feedback from other stakeholders of the project. The other stakeholders could be examining the plan either through head-mounted displays or a CAVE installation, having a more immersive experience of the plan.

This initial concept would later be validated and refined in collaboration with city planning professionals.

4.2 *Joining a study group with city planning professionals*

To be able to design software in the context of city planning, it is essential to have sufficient knowledge about the issues in that field of profession. Some of this knowledge can be gained by literature review, which was performed previously, but to gain deep insight into the issues with real-world city planning projects, a reflection with city planning professionals are required. For this reason, this research was performed in collaboration with a study group in a project called URBS-data, organized by Aalto University.

This group consists of the usual stakeholders of city planning projects, such as architects, contractors, landowners and city authors. The organization is described in Image 15. In addition, the group included scientists and software developers, who would create academic and technical solutions to the issues that are identified in the group. The high-level goal of this study group is to reform city planning processes and city planning tools. The focus is on finding solutions regarding issues with usability and the utilization of available data with planning tools and virtual reality tools. The key interests of the study group are the development of participative planning support systems (PPSS) and novel concepts that enable data integration collaborative production of knowledge. An essential part of this study group is the big room approach, which is a trending methodology in city planning projects because of its effective nature of sharing knowledge between stakeholders.

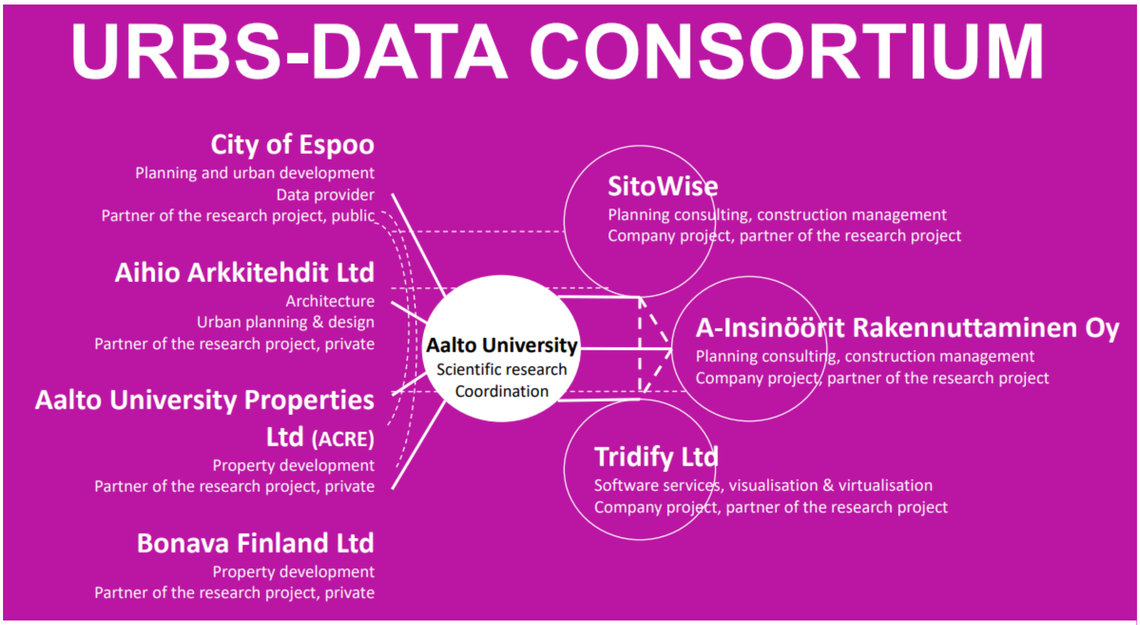

Image 15. URBS-data organization diagram

4.3 Big room method to collaborative planning projects

The big room method is a descriptive name for this method. In the big room approach, all the available participants of a project are gathered in the same big room and will work towards the project's goals in collaboration. In contrast to traditional meetings, the big room method suggests that actual substance work, like programming, should be done in the big room sessions, instead of just discussing and making decisions on the matters at hand. The big room method also encourages as many participants to join the sessions as possible, and the sessions are not formal meetings, where everybody should pay attention to the presenter at all times. Instead, big room sessions are more workshop type of gatherings, where people may work in one large group, smaller teams or even individually. Big room sessions also last much longer than traditional planning meetings, and many times can be all-day sessions. Ideally, the whole planning process would be executed with big room method, where all the participants would work mainly in the big room during the project, however, this is rarely achieved, because often the participants are involved in other duties as well, and can't spend their whole working time in the big room. That said, transportation to the big room can be an issue as well, which makes it difficult to be present as much, and which is why the big room should be located in a pivotal location, in regard to the participants.

The reasoning for the big room method is that when all the participants of the project are located in the same room, the communication between stakeholders becomes immediate. Traditionally asking a question from a few stakeholders would require a well-thought email to be written for each, and waiting for the reply from minutes to weeks. In a big room, everyone will be able to discuss the project with other stakeholders at any given time, greatly reducing the time to make decisions. The exchange of information also becomes very natural, and this helps much more information to be communicated. Instead of just a few bullet points on an email, the participants will be able to have an in-depth conversation with other participants. Big room method also enables participants to present their ideas and accomplishments to a large audience and getting instant feedback from other professionals. The participants can help each other out in their tasks, which is very useful if the room is full of dedicated professionals in their own field. This way, the big room method is a powerful way to learn continuously, as there are always new findings presented in a big room, and participants will always have people around them to help them comprehend new concepts. One of the most valuable aspects of the big room method is that participants may find great contacts and grow their social networks, which may be a great asset in future projects.

In the URBS-data study group, big room sessions were arranged approximately once in a quarter. The big room itself had a CAVE installation, which was used for presentations in virtual reality. The big room also contained common equipment for design tasks, such as markerboards and flip charts, and portable workstations, which could be arranged for individual work as well as for teamwork. The big room used in this project is displayed in Image 16.

Image 16. The big room used in the URBS-data project

The project was started with a kick-start session, where goals for the project were stated, and all of the stakeholders introduced themselves so that everyone got some understanding of each stakeholders' skills and specialties. In this session, the stakeholders also worked on their individual goals for the project, and other participants were able to comment on them. This session allowed participants to exchange contacts so that they could stay connected outside the big room as well. After the first session, the participants arranged further meetings with those participants that had similar interests in order to get to know them better and see if they can benefit from each other during the project to achieve their individual goals. These meetings were also exploited to see if there may be some potential collaboration and partnerships outside the scope of the URBS-data project.

The study group included a management team, which would meet up before every big room session, to plan the structure for the next session. These meetings were crucial for the big room sessions to be successful, as the agenda that they designed for the big room sessions made the activities in the sessions diverse and appealing. This way there was a good balance of presentations and demonstrations, teamwork and discussions, individual work and free time in the schedule, which kept the sessions fresh and compelling. After each big room session, follow-ups with the closest participants took place, to have in-detail discussions about their latest developments. An important part of this project was also the individual work between the big room sessions. As the sessions were held only once in a quarter, it was important that some development was done outside of the big room as well. During this time, further designs and implementations, for instance, could be made and presented in the next big room session. If the big room working was continuous, and there would be sessions every day, then this kind of individual work would not be necessary, and all the work could be done in the big room instead. After two years, when the URBS-data project was coming to its end, a final session was arranged, where each stakeholder presented the work that they had done during the project and evaluated their success in respect to the goals, they had set in the beginning. Finally, the management team made a survey for the participants, which was used to evaluate the overall success of the project, the workshops, and methods that were used. This was a very well structured and managed big room project and sprouted many impressive findings, products, and further projects.

4.4 Refinement of the initial concept for virtual reality city planning tool

Before starting actually to design the planning tool, the initial concept was reflected with feedback from city planning professionals, including decision makers, contractors, and architects. First, this reflection was done in a general discussion with the study group in a big room session. The city authors and other decision makers showed interest in having collaborative features in the tool, that would enable the public to participate and the planning process. The tool should also be easy enough to use, that the public could use it autonomously. The contractors, on the other hand, did not feel this kind of tool would be of any interest to them, and that the models they use in their work need to be highly accurate technical models, and a virtual reality-based visualizing and modeling tool would not be precise and informative enough in their use cases. The architects showed the most interest in this concept, and they stated that a good implementation of this kind of tool could potentially speed up their work drastically. They mentioned that the software should have the capability to add metadata to the elements in the city and that the modeling should definitely be possible with a regular desktop computer without any special virtual reality devices.

After the first big room session, interviews with the architects were arranged for more detailed input about their use cases and needs. This interview revealed that currently, the architects are making the models with SketchUp, or similar 3D modeling tool. The biggest issue with their workflow was that the work is very time consuming and repetitive. Even if the city model consists of box-shaped buildings, which are positioned in repetitive patterns, the architect has to construct each model separately. This also makes it a relatively big task, if a lot of modifications are requested to the model by the decision makers, which usually makes it impossible to make the modifications in the same meeting as the requests are made. The architects mentioned that some kind of copy and paste workflow could work well in their use case. They also said that it would help a lot, if the software had some kind of catalog of buildings and city blocks, that they could use to add preset models to the city plan easily. The interview also revealed that the earlier mentioned metadata for the buildings should include floor areas of buildings, potential population of residents and the working places that the area would generate. These are metrics that are essential in city planning projects, and the architects very often design the models according to these metrics. One special request also came up in the interview: Sometimes the architects are asked to perform some changes to all of the buildings in the plan, such as changing the roof types of the buildings. This can be a very tedious task, and if it could be solved with a simple solution, it would greatly reduce the workload of the architects, when such requests arise.

4.5 Design and implementation iterations

The design and implementation of the virtual reality tool are performed in iterations. After each iteration, the implementation is presented in a big room session, and further feedback is gathered, which are then applied to the design and implementation of the software. This allows adjustments in case of misinterpretations of earlier input from the literature review or previous expert analysis. This chapter describes the evolution of the software through those iterations.

4.5.1 Iteration 1: Design

The first design was made very simplistic to produce a clear and easily comprehensible user experience. The design principle here was to minimize the effort required to perform a design task in the application, with respect to the keystroke-level model (KLM) [Car80].

A click based road construction feature was the first feature to be designed. At this point of research, the assumption was that creating the roads are the very backbone of the modeling process, as is suggested in the study by Nguyen et al [NNV16]. The click based approach would allow the user to create roads with minimal effort, by pressing and holding control-button (Ctrl) while adding vertices to the path on the terrain surface. This path would then be used to construct a road following this path computationally.

A randomized building generator was designed to be used to populate city blocks semi-automatically. This would prevent architects from having to model each building separately, and would potentially increase the design workflow dramatically. The initial design was that an area would be selected on the terrain, and an intelligent algorithm would then generate a sensible layout for buildings for that area. The algorithm would take resident counts and job counts as parameters, which would decide how much floor area is needed, and how dense the layout would have to be and how tall the buildings would have to be to realize the given parameters.

Navigation in the virtual environment was designed to be a simple free 3-dimensional navigation that is used in game engines and 3D modeling software, because architects are used to such interface, and it is an accurate and effective way to navigate through the model.

Finally, terrain manipulation features were designed, so that users would be able to create terrains with landforms that are equivalent to landforms of the real world areas. This feature was designed as a brush tool, that would either elevate or lower the landscape with left and right mouse buttons.

4.5.2 Iteration 1: Implementation

The first version, as well as the following versions, was implemented with the Unity game engine. A lot of groundwork had to be done regarding input controllers and user interface before the actual features could be implemented, which is why the implementation of this version required a lot of effort. For this reason, the randomized building generator was not completed yet for the first version. The road constructor tool utilized a polygon creation plugin that was available for Unity, but this plugin had issues with performance if the user tried to make curved roads, which decreased the user experience. The terrain manipulation tool utilized Unity's own terrain system, which was easy to use and well suitable for this purpose. The navigation functionality was implemented from scratch and resembled the navigation tools from game engines and 3D modeling software, although this was just a basic implementation with forwards and backwards movement and rotation, unlike the feature-rich navigation tools from more sophisticated applications. Overall, the first version was very simple. On the application start, an empty plain of grass would appear, and two buttons in the upper left corner for activating either terrain manipulation tool or road constructing tool.

4.5.3 Iteration 1: Feedback

This first version of the software was not well received by the study group when the software was presented in a big room session. The user interface was found unattractive, and the constructed roads were said to look unnatural. It was suggested, that road construction inherently includes so many complexities, that this kind of work should be done in more sophisticated software. The terrain manipulation was found somewhat unnecessary, and instead, it was pointed out that this kind of software should have the ability to open existing models, with terrain already in place. As the randomized building generation was not yet implemented in this version, no concrete feedback from that was given. However, the design for such a feature was found fairly interesting, but it was pointed out that it would be much more important to have a catalog of preset buildings and city blocks, that could be used to add those models to the plan easily. The non-technical stakeholders found that the navigation was not user-friendly, although the architects were able to use the navigation with ease. Some architects were missing some of the navigation features from other modeling tools, especially the panning feature. Overall, this feedback indicated that the approach taken in the first design was not much appreciated. More focus needs to be put on developing a more appealing user interface and user-friendly navigation, and it should be secondary to design a KLM optimal user interface.

4.5.4 Iteration 2: Design

In the second design, the road construction and terrain manipulation tools were stripped off, and most focus was put on the development of building creation features.

As the previous feedback implied, buildings should be allowed to apply from a catalog of presets of buildings. This is achieved in a drag and drop style interaction, where the user can browse a catalog of items and simply drag the item on the terrain, and it would be instantiated on that location.

A new approach to building construction was designed, where the user could easily manipulate the length, width and height of an instantiated building with simply dragging handles located on the sides of the building, when the building is selected. The user could also change the texture of a selected building, to change the ambience of the area with a few clicks.

Opening and using existing terrains is also included in this design. This would require a connection to a database of such 3D models. On the same note, the collaborative planning with the same model over the internet should also be available, as was implied in the initial concept refinement session.

Navigation should be changed, so that the movement around the model could be done smoothly and with ease, to satisfy non-technical users as well. First person navigation should also be implemented, as this is the most important perspective to gain an immersive perception of space and scale of the city.

4.5.5 Iteration 2: Implementation

The second version was started from scratch and was built on the Tridify platform, which is also based on Unity. Tridify is an extendable 3D modeling environment, which provides many features out-of-the-box. The reasoning for this, is that the feedback from the study group reveald that there are a mass of small features that are expected from a city planning modeling tool, that did not arise in the concepting and interview sessions. One relevant feature in this context, offered by Tridify, is a drag and drop catalog, displayed in Image

17, which allows arbitrary objects to be dropped from a catalog to the terrain. Replacement, copying and pasting, rotating and deleting of these objects are also provided by Tridify, which are displayed in the Tridify’s selection toolbar on Image 18. Other useful features for city planning, are sunlight hue and position manipulation, great navigation tools, including first-person mode, bird-eye mode, and freelook mode, animation creation tool and separate modes for visualization and modeling tasks.

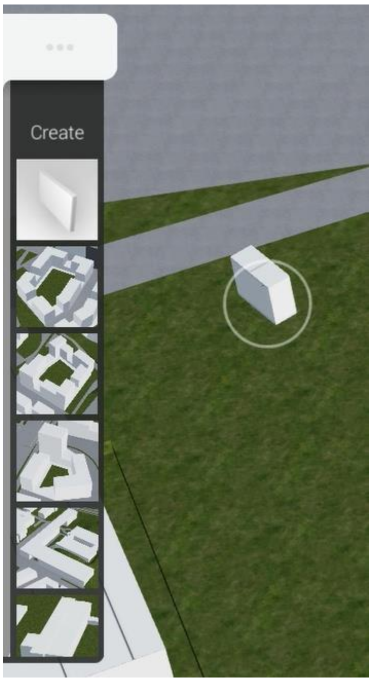

Image 17. Tridify's drag and drop catalog

Image 18. Tridify's selection toolbar

The editable buildings were implemented using Tridify's smart object framework, which is an extendable framework for adding new models to Tridify's catalog and program custom behaviour for them.

One of the biggest selling points for building on top of Tridify was that Tridify offers login within an organization and allows users to save their plans to their cloud servers, enabling collaboration between users within the same organization. The cloud connection also enables users to access Tridify's smart object catalogs, which includes a lot of relevant objects for city planning, such as trees, plants, benches, and cars.

4.5.6 Iteration 2: Feedback

Now that the software was built on top of the Tridify platform, the user interface was found to look appealing. This fact alone engaged many more people in the big room to try the software out and use it for a longer period. The decision makers were pleased with the first person mode, as it was found very immersive on the CAVE installation. The placement of buildings was also easy, although manipulating them was too limited, and just having cubic buildings would not be enough for the usage for city planning. Changeable textures for the buildings were found unrealistic and unnecessary as well, and it was suggested that the buildings could simply be white, which is very common when city scaled models are designed. Navigation was found to be natural, and was suitable for all users, as Tridify provides different camera modes for different use cases. The building creation features were not sufficient on this version yet, and many participants claimed that there should be more options in the catalog for buildings and that the manipulation tool for buildings should allow more complex structures to be made.

4.5.7 Iteration 3: Design

This iteration focuses on improvements to the building creation workflow of the tool.

First, the cubic building object was replaced with a more sophisticated building creation tool, which gives users more freedom to design the buildings to the shape they want. This tool utilizes paths, to draw an arbitrary path shape on the terrain, which will then be computationally extruded into a building shaped 3D model. The path-based building creation tool is displayed on Image 19. The ability to change textures was removed, and all buildings are white, though depending on the lighting, the buildings are visualized with different shades.

Image 19. Path based building creation tool

A dozen of presets of buildings are added to the catalog, to cover the most common models that are used by the architects, as well as some more complex structures that can be used as city blocks, as well as examples on how complex structures can be created with the building creation tool.

A save function is also added to the design, which allows the user to save the created buildings to the catalog. This way the catalog presets are not limited to the default presets available but can be extended with buildings created by any user in the same organization.

4.5.8 Iteration 3: Implementation

The implementation for the third version was continued work on the previous version. The whole building creation tool was developed using Tridify's smart object framework, although minor extensions were required in the framework itself.

Saving the presets of buildings to the catalog required some custom modifications to the Tridify platform, as the platform did not support such functionality out-of-the-box.

4.5.9 Iteration 3: Feedback

This time feedback was mainly positive, and the building creation tool was well received. It was said, that it is intuitive and easy to use, yet the users could make complex enough structures with this tool. Saving the created buildings as presets was also found very useful and it could save a lot of time especially when starting with a new project, as the presets from previous projects would be available. However, the study group pointed out, that color coding for the buildings should be allowed so that they could be categorized for various purposes. For example, commercial buildings could be colored with blue color, and residential buildings could be colored with red color. Also, as was discovered in the initial big room session and the following interviews, the floor area data should be made available for the user. Similarly, the number of floors in a building is not defined, even though it is an important factor in the planning process.

4.5.10 Iteration 4: Design

The final design of the tool builds upon the previous implementations and received feedback. This time no features had to be removed from the design, and the added features are mere enhancements to the previous version.

The automatic floor area calculation was added to the final design. This allows users to immediately see what the combined floor area of the selected buildings is, which is demonstrated in Image 20. It was also considered, whether or not an automatic calculation for resident potential and job potential should be included, but as this is merely a division of the floor area, it was left out of the design.

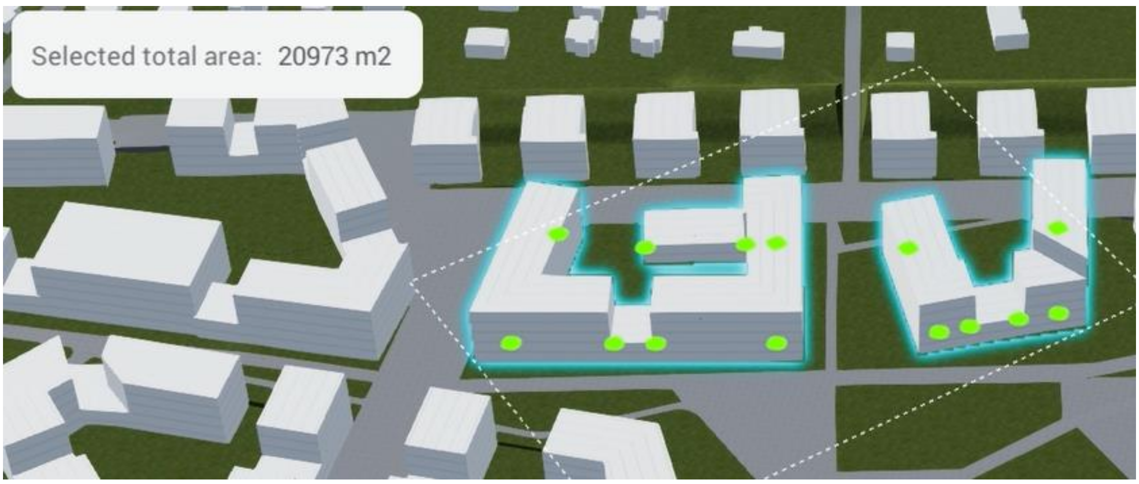

Image 20. Automatic floor area calculation tool

The building height setter was changed to be based on the number of floors, which is displayed in the smart object context menu in Image 21. Therefore, modifications to buildings' heights can only be made in full floors, making the designing more precise. This also gives accuracy to the calculation of floor area. Because of this change, the height of a floor required a setter as well, which is designed to be a numeric field in a context menu of a selected building.

Image 21. Smart object context menu for a building

Color coding for the buildings is also applied to the design. This is actually a re-introduction of texture change functionality that was already implemented earlier, but now the textures merely have plain colors, instead of graphics imitating real-world buildings.

4.5.11 Iteration 4: Implementation

Implementation of these changes was merely adjustments and small changes to the user interface, as these features rely on the already implemented features from previous iterations. Therefore, implementing these features took relatively little effort.

The fourth iteration was the final iteration, yielding the final version of the implemented virtual reality city planning tool, which is demonstrated in Images 22, 23 and 24.

Feedback from the other stakeholders was not received from this version, as it was merely presented in the final big room session, and the audience did not have a formalized chance to provide feedback. However, the tool was tested with a group of people, and qualitative analysis was performed on the test results. This test and the results are described in the next chapter.

Image 22. Masterplan viewed from bird-eye perspective

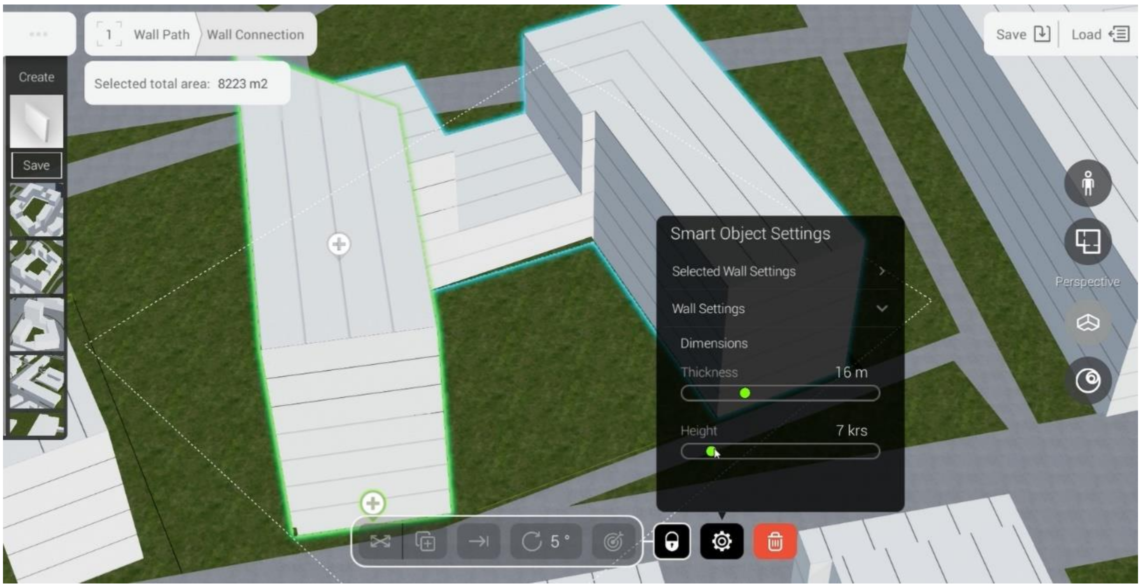

Image 23. Complex buildings created with the building creation tool

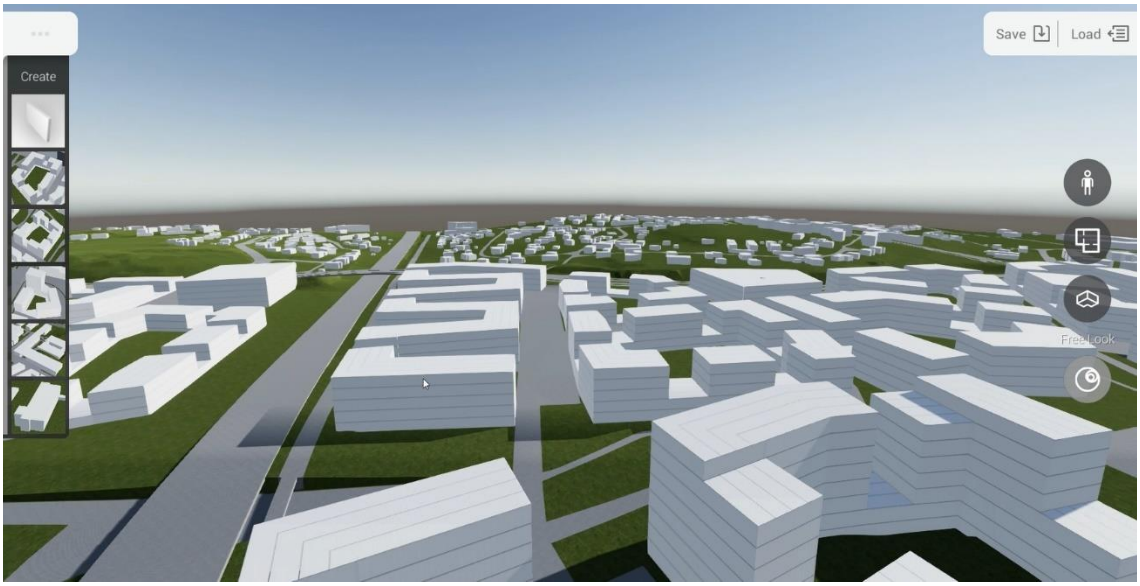

Image 24. City plan from a free-view perspective

5 Testing and evaluation of the model solution

To evaluate the implemented tool, an analysis of the functionality of the implementation is required. This is performed by executing tests on the implementation and analyzing the test results. This chapter describes the test setup and results of these tests.

5.1 Test setup

The tests included 8 participants, who are students of urban planning in Aalto University. The participants have varying levels of skills with traditional modeling tools. The participants were given a design task, which they first executed by using SketchUp, which is a commonly used tool for city modeling. After that, they executed the same task using the virtual reality tool implemented here. After performing these tasks, the participants answered a survey, in which the participants were asked to compare various aspects of the two tools in a qualitative manner.

5.1.1 City planning task

The participants were asked to design the area of Otaniemi so that the gross floor area of in the area is maximized. The goal was to maximize the number of infill buildings while maintaining or improving liveability in Otaniemi, with respect to the participants' prior understanding of Otaniemi as an area. It is worth mentioning that the participants are students at Aalto University, which is located in Otaniemi, so the area is more or less familiar to the participants. Some of the participants even live in this area. They have also been taught about the concept of liveability during their studies.

5.1.2 Survey

The survey was divided into three sections. The first section was a comparison of SketchUp and the model solution based on performance on the given task. The second section was an expert analysis focusing on other potential use cases for the tool, based on participants' understanding of the tool gained so far. The third section was a general feedback section, which allowed participants to give informal feedback on the tool.

The task performance based comparison section asked participants to compare the learning curve, perception of scale and space and task execution time of the model solution and SketchUp. As more specified questions, the participants were asked to compare the ability to keep track on the gross floor area and the re-usability of the already created models, as they were features that were relevant to city planning and the performed task.

The section of expert analysis on other use cases, based on understanding already gained of the model solution, requested the participants to compare SketchUp and the model solution in communication between stakeholders, collaborative designing and modeling, engagement of the public and teaching tasks. Although these tasks could not be performed in the test setup, an expert analysis on them was performed because they are essential use cases of the model solution.

In the general feedback section, the participants were given an opportunity to freely give feedback and suggestions about the model solution. They were also asked about the advantages and disadvantages of the workflow with the model solution and were asked if they would be interested and willing to use such a tool on their future city planning and design tasks.

5.2 Test results

The participants were asked to compare the features and qualities of the model solution with SketchUp. Here is a composition of the answers they gave.

5.2.1 Comparison in learning curves

The model solution was found very easy and intuitive to learn. Partly this is due to fewer features in the model solution, resulting in a simpler user interface with fewer icons. Especially the building creation tool was found very easily learned. The problem of learning to create buildings in SketchUp was that there were many tools required in the process, and learning to use all of them took a lot of effort. In contrast, with the model solution users were able to start creating buildings immediately. There were, however, some minor issues with navigations that were not intuitive to some users. For experienced users of 3D modeling software, the comparison was hard to make because both tools are easy to learn and use. However, if more detailed designing is required, then SketchUp was preferred because making complex shapes in the model solution was very difficult.

5.2.2 Comparison in the perception of space and scale

The perception of space and scale was found to have very few differences in model solution and SketchUp. The most notable differences were in the graphics quality and realism, which were found to be better in the model solution. If trees and other objects were used in the design, then the model solution provided a significantly better understanding of space and scale than SketchUp. Some users with more experience of 3D modeling software thought that SketchUp provides a better perception of space and scale, because the navigation tools with SketchUp are more powerful, allowing the user to quickly view the plan from different points of views.

5.2.3 Comparison in execution times of the task

For users with extensive experience of 3D modeling software, the execution time was found to be about the same with both applications, because complex structures were faster to create in SketchUp, but on the other hand placement of the buildings, and creation of simple structures was faster in model solution. Less experienced designers found that the task was completed much faster with the model solution, as the building creation tool was very easy and efficient to use, and there were less trial and error than with SketchUp. Moreover, the catalog of preset buildings made designing even faster with the model solution. However, it was pointed out, that the test setup may have been somewhat biased to the model solution's favor because the task was first performed with SketchUp. As the participants had already completed the task with SketchUp, they had a mental image of what they want to achieve with the model solution, allowing them to perform faster with the model solution.

5.2.4 Comparison in keeping track of gross floor area

The results of this comparison were clearly divided. This was due to the fact that the participants had differing ways to keep track of the gross floor area in SketchUp. Some participants were able to see the total floor area the whole time they were designing their plan and found that it was somewhat troublesome to keep track of the area in the model solution, as they would have to select all the buildings for this information. However, some participants had to go through all their buildings in SketchUp and manually calculate the gross floor area, by measuring the widths, lengths, and heights of the buildings. Naturally, these participants found the area calculation feature in model solution to be extremely helpful and easy to use.

5.2.5 Comparison in re-usability of buildings

This comparison revealed that the design workflow with SketchUp definitely required re-using the buildings they had already made, by copying and pasting them and making some modifications to the duplicates. In contrast, the building creation tool of the model solution was easy enough to use, that some participants did not feel the need to re-use the buildings, and instead created each building from scratch. On the other hand, some participants did not find the copy and paste functionality in model solution at all, so they could not compare. Overall, the re-usability was found very similar, or a little better in SketchUp.

5.2.6 Comparison in communication between stakeholders

Most of the participants found the model solution to be better for communicating ideas between stakeholders because it had nicer graphics, clearer edges in the buildings and it was fast to navigate through the plans. The model solution was also found to be good for creating quick designs and drafting ideas to be communicated with other stakeholders. Though, the most experienced designers preferred SketchUp, because it allows communication on a more detailed level, and also supports 2-dimensional presentations.

5.2.7 Comparison in collaborative designing

In the comparison of collaborative design use cases, the answers revealed that SketchUp was thought to be more useful. This is because the designing was thought to be mainly in collaboration with other architects and that most architects would prefer using more detailed applications, such as SketchUp, rather than a high-level designing tool, as the model solution. One participant also felt that the model solution is suitable for individual work exclusively. However, it was pointed out that the Tridify cloud platform makes it easy to share plans and work on them in teams, so this gives some advantage to the model solution.

5.2.8 Comparison in engaging the public

Most of the participants found the model solution to be much better for engaging the public to city planning processes, as the user interface is simple and intuitive, and the ability to share plans with Tridify's cloud platform brings the plans available to the public with ease. Only one experienced participant felt that SketchUp would be better for engaging the public, arguing that it is important to be able to engage the public with more detailed plans than what is possible in the model solution.

5.2.9 Comparison in teaching

In the comparison of teaching people about urban areas, the model solution was found better, if merely the general overview of the are is required, but if the plan should include more detailed data for teaching purposes, then SketchUp would be preferred.

5.2.10 General feedback

The model solution was generally found very easy to use and an effective tool for making quick drafts. It is good for massing buildings for high-level designs. The ability to use ready-made presets of buildings and modifying the buildings with ease with the building creation tool was found to be pleasant to work with, and the placement of the buildings to terrain helped a lot in the design process. The participants felt that this would be a great tool to communicate ideas at a fast pace on a city scale plan.

The participants thought that the model solution should have improved and more detailed modeling abilities, so that the shapes of buildings could be more arbitrary. Some participants also thought that the camera movement was too limited and that the movement in first person mode was somewhat clumsy. It is worth noting though that these participants only used the tool in Tridify's bird-eye and first-person modes, and they did not realize that a freelook mode was available as well, which would allow free movement around the virtual environment. Some participants also pointed out, that the shadows were cut off when the plan was viewed from the bird-eye perspective. This is a feature that could easily be fixed, although increasing the shadow drawing distance would affect the performance of the application. The participants also stated that the area calculation should take into account buildings that are placed inside one another.

All of the participants would use the model solution for similar tasks in the future if the tasks are performed with a high-level plan. In more detailed work, they would prefer other tools to be used.

Overall, the model solution was very well received, and the participants were eager to see further developments of this tool.

This chapter described the tests that were held in order to evaluate the effectiveness of the implemented tool, especially in design tasks. A detailed report was then given, where the qualitative results from a survey to the participants of the test were composed. The next chapter draws conclusions of the overall research process and answers the research questions.

6 Conclusions

6.1 Findings

The research studied the usage of virtual reality technology in city planning projects. Some goals for this research were to analyze what kind of virtual reality software is already available for city planning, what kind of new software would have the most potential in the markets and how could virtual reality technology by utilized on such software.

From categories of viewing (visualization), modeling and simulation software, the category that has the most applications in the markets, is the visualization category. This category is the most researched one, probably because the greatest benefits of using virtual reality technology is its superior ability to visualize and provide realistic perceptions of city-scale 3D models. This makes the visualization category to have less potential in the development of new products, as it would be difficult to devise an application with a unique perspective to visualization software.

The category of simulation applications, on the other hand, is a less studied field, even though some applications have been produced in recent years to this category as well. While there is no doubt, that there would be markets for new innovations in this category, the inherently complex nature of applications in this category makes it very difficult to develop new virtual reality simulation software. The developer would not only have to be familiar with city planning processes but would also need specialized knowledge about the simulation subject that the application targets. For example, traffic simulations are its own field of study, and to familiarize oneself to this field would be a lot of work. As this research is fundamentally a software engineering research, with cross-sectional aspects to city planning, including a third field of study would be too much work in the context of this research. Nonetheless, with enough time and effort, developing virtual reality applications in this category could indeed be very interesting and successful.

For the aforementioned reasons, the most potential category for developing new virtual reality software is the modeling category. However, the model solution implemented in this research utilizes also elements in the visualization category, as they are the strongest selling points of virtual reality technology. The implementation enabled the usage of head-mounted displays and CAVE installations for viewing the plan, as well as traditionally used computer monitors, and these could even be used simultaneously, allowing passive users to view the plans in the software, and an architect to modify the plan at the same time.

The analysis of the implemented software revealed, that the implementation was well received by designers, and had a unique perspective to city planning tools utilizing virtual reality technology. With some refinements and additional features to the user interface, the model solution could indeed have an audience in the city planning tool markets.

Another goal for this research was to find out what features has the most value for city planning professionals and what kind of user interface is required and desired to use those features. The iterative design process revealed, that especially the non-technical participants of a city planning projects appreciate a polished and clean user interface, with a set of user friendly navigation and building construction features. Functionalities to make more complex or highly accurate models did not gain much interest in the audience, and caution needed to be taken to avoid the application to become too technical and rigid with the occurring feature requests, as if the application would have become too technical, it would not have the advantage to CAD software, in terms of usability and simplicity. Road construction features is an example of such a feature that is inherently so complex, that it was best to leave for more techinical, mature and feature-rich software.

The final goal for this research was to evaluate the feasibility and performance of the implemented tool, in comparsion to alternative tools in the market, and SketchUp was chosen as the alternative tool to compare to, as it is widely used in the architectural design of urban areas. The test results indicate that the implemented tool performed very well in some scenarios and were clearly inferior in other scenarios. For users that has no prior 3D-modelling experience, the tool seemed to work very well, proving the usability and user friendliness for non-technical audience. The tool also had some features specific to the context of city planning, such as drag'n'drop and ground-snapping of buildings, which made parts of the tasks much faster. However, for experienced SketchUp users, the tool did not feel conciderably faster or more efficient, and as it's missing a mass of features that 3D modelling software has, the experienced architects were not too impressed. That said, the less experienced the user and the more city-planning-specific the use case is, the better the implemented tool performed in comparison to SketchUp.

6.2 *Future research and development*

This research covered a broad overview of virtual reality technology in city planning projects, but there is also room for further research and development of the model solution. Some suggestions for development were described in the result section of the tests, and those include improvements on the navigation interactions and functionality for more detailed modeling. The development of interactions for other input devices would also be an interesting branch of work, such as using spatial controllers or haptic gloves in the design process. For further evaluation, the model solution should also be studied in more comprehensive tests, with other stakeholders of city planning projects involved, as these tests were performed solely by architectural design experts. Experiments of engaging the public to the planning process could also be performed, but this would require some development on the authorization features of the Tridify cloud platform or an implementation of a custom platform that enables the public to view and provide suggestions on existing city plans.

The next chapter contains discussion and reflection on the overall research project, including issues of the research methods, discussion about time and scope management and challenges that were faced during the research.

7 Reflection

7.1 Topic

The topic of this research was decided when the latest wave of virtual reality technology was emerging, and there was a lot of discussion about virtual reality's future. As more research about the virtual reality technology was done in this study, the concept of virtual reality itself started to seem vague. Previously, the author's understanding of virtual reality was limited to immersive experiences using head-mounted displays, but after getting to know the history and various usages of virtual reality, the term itself started to feel very intangible. This was one of the greatest issues in the early stages of the research. Change of subject was also considered at this point, but after all, it was decided that the topic merely required some clarity and that the term "virtual reality" would have to be defined in the context of this research. This was not an obvious task since there are many conflicting definitions for virtual reality, but after joining the city planning study group, the term was defined to reflect the understanding of virtual reality by the city planning professionals. After establishing a clear definition for virtual reality, the research topic became much clearer and focused.

Another issue with the topic is, that as the virtual reality technology is developing in an extremely fast pace, there was new technology becoming available during the research, which forced some parts of the research to be revisited and lengthened the completion time of the research. A solution to this would have been simply to work on the research more intensively to finish it in a shorter period of time. However, the timing was not entirely in the author's hands, since the research included connections with the study group.

7.2 Contributions of the study group

Joining the study group helped remarkably in understanding the issues that city planning projects suffer. This was an invaluable asset when designing the model solution, and without the insight of the other participants in the study group, always available to the author, the design and implementation of the model solution would not have been possible. However, doing this research in the study group also introduced some problems. Since the group gathered only once in a quarter during a period of two years, this also affected the time management of this research. In order to gain as much valuable input from the study group, many design and implementation iterations would have to be done, but as each iteration would take the minimum of three months, or even six months in those cases when the author wasn't able to participate in a big room session, the whole project becomes very long. This is also a problem because of the rapid development of virtual reality technology, which could make earlier findings in the research invalid. Another approach to gain understanding and feedback on the research topic would have been seeking out such experts that were in the study group, which could have made the research process faster. However, since the author did not have any previous experience in the field of city planning, it would have been hard to identify such experts, let alone engage them to co-operate with this research.

7.3 Scope management

Managing the scope of this research was also a difficult task. With each iteration on the implementation, new feature requests would arise, and it was very tempting to arrange further tests with larger groups and different stakeholders. Including tests and extensive research about various virtual reality devices also seemed very important in the early stages of this study, but such tests and research were left out of the scope of this study, as they were not relevant to the study's topic, in respect to the clarified definition for virtual reality. In the author's opinion, the scope of this study is already quite large, considering that this is a master's thesis level research. On the other hand, if the research would be scoped to be exclusively a literature review, without any design or implementation tasks, then the literature review could have been done in a more extensive manner. Overall, the scope of this study composed a coherent combination of different research methods and, in the author's opinion, was successfully managed.

7.4 Evaluation of the study methods

This study was performed using multiple study methods; literature review and analysis, applying a model solution on multiple software tasks and analysis of the functionality of the implemented system. The risk of this approach was that the scope of the study would become too large to handle, or that the methods would not be applied adequately. However, these study methods demonstrates an end-to-end workflow of a real-world software development cycle, and all the methods were necessary for being able to produce a system that have potential for future developments.

The literature review was an important first step to gain understanding on the topic itself. Before the literature review, I was playing with the idea of implementin haptic devices, which could be used in modeling, and thought that this would be a very modern solution which is not yet explored. However, the review revealed that such devices have existed for decades [TNN98], and that there is no point in replicating the existing studies.

The interviews held on the concepting phase was not absolutely necessary for this study to be succesful, but as they only took a few hours of work, they were definitely worth the effort. I gained a lot of knowledge about the concrete features that the architects wish to have on their tools, and forming an initial concept without these interviews would have resulted in a much more immature concept. Gaining the same knowledge in the big room sessions may have taken many sessions, so these interviews made the overall development much faster.

Development in iterations is a standard agile way of software development, and therefore the implementation in this research was done that way as well. However, the methods used in this research was not smoothly translated to software engineering tasks. First of all, the iterations were a few months of length, in contrast to traditional Scrum development, where the iterations are 1-4 weeks long and all focus in on one project at a time. Besides that, the iterative development method was natural here, and resulted in a refined product. If the big room sessions would have taken place once in two weeks, this method would have resembled very much those methods used in commercial software development projects.

Finally, the tests with the final product were crucial, in order to evaluate the success of the overall project and gain inspiration for future development. Without the tests it would have been difficult to validate, wheter or not the previous methods resulted in a desirable software. To recapitulate, even though this study required patient and quite a lot of work, it definitely resulted in valuable findings and in author’s opinion, the choice of study methods were appropriate in respect to the study goals.

8 Acknowledgments

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